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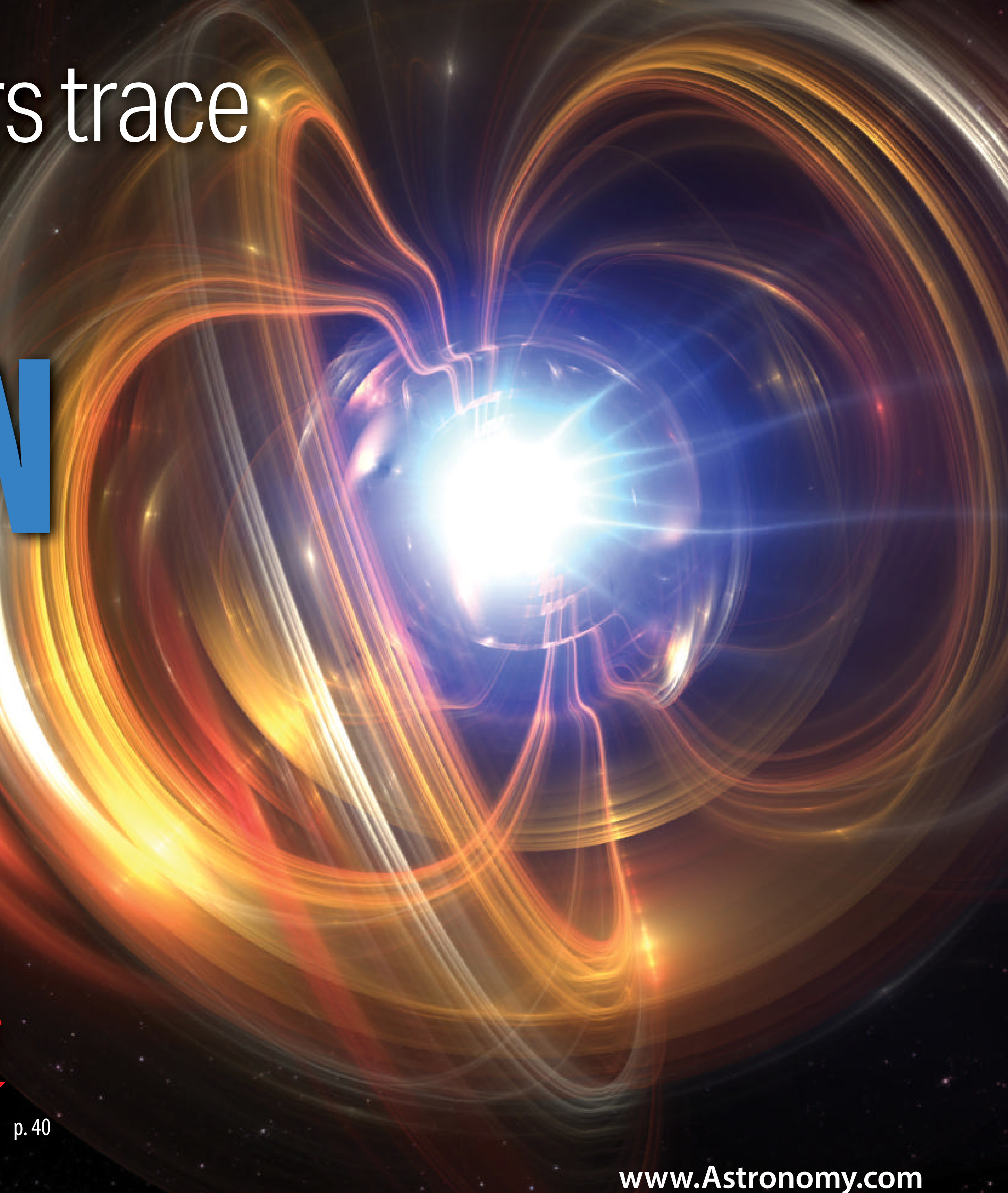

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Quantum entanglement — two particles intertwined by quantum mechanics — may hold secrets to understanding time. JURIK PETER/SHUTTERSTOCK

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FROM THE EDITOR

Star Trek and science

Small, furry, and fast-multiplying, Tribbles hail from Iota Geminorum. PARAMOUNT/ COURTESY: EVERETT COLLECTION

When I was a kid, a new series lit up the television: *Star Trek*. I was hooked on watching what is now called *The Original Series*, with Kirk, Spock, McCoy, and Uhura. In this month's "An Observer's Guide to *Star Trek*" (page 40), Contributing Editor Michael Bakich takes you on a tour of many of the star systems — from Alpha Centauri to Canopus to Wolf 359 to 61 Ursae Majoris — mentioned in various episodes of the show.

While it lasted, the ability of *Star Trek* to swoop us off through the galaxy was priceless. Clearly many working scientists in today's world were influenced and inspired by the series. As much as we may adore it, it's important to remember that *Star Trek* is science fiction. Of course, this may be obvious in a scene where a rock-creature that moved at a fraction of a mile per hour was a menacing monster, or in illusory worlds where bringing Abraham Lincoln back to life as a spiritual advisor or recreating the gunfight at the O.K. Corral was the norm.

But warp drive engines that carry a spacecraft (which has lots of mass) at velocities faster than light are also nonsense. The transporter, scrambling atoms in something as complex as a human and reassembling them, ain't gonna happen. A tricorder to immediately diagnose the overall character of all attributes of living or inanimate beings is silly. And I'll never completely know why most of the aliens were bipedal beings with two legs and two eyes, or why most of them understood English.

Star Trek also offered lots of evidence of things that were more logically plausible, though — communicators, holograms, replicators, phaserlike weapons, artificial gravity, matter-antimatter generation, and more.

Reality was never the point with *Star Trek*. Inspiration was. For those of us who made the trip, it helped us to hold onto our imaginations as we learned more about the real cosmos we're in.

Enjoy the journey.

Yours truly,

David J. Eicher
Editor

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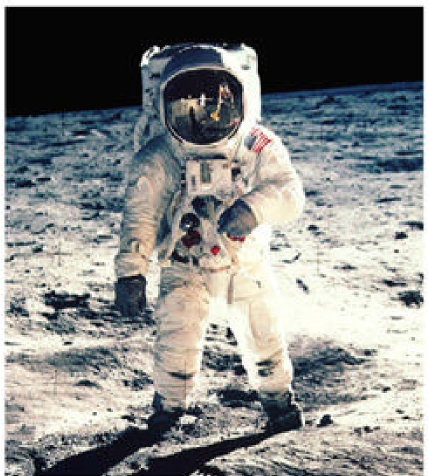


Neil Armstrong and Buzz Aldrin first set foot on the Moon on July 21, 1969 — if you lived in the U.K. NASA HISTORY OFFICE/THE NASA JSC MEDIA SERVICES CENTER

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

The malleability of time

I enjoyed Mr. Shubinski's informative article, "Defining time" (December 2021), very much. It sparked a memory of 2019, when I was reading a special edition magazine about the 50th anniversary of the Moon landing. It said that Neil Armstrong first walked on the Moon on July 21 — "What? Wait! Is that a typo?" Then a stray possibility flitted through my brain. I hunted at the front of the magazine … yup, U.K. Of course, they were correct — by Greenwich Mean Time. It appears that dates and times may still float on a sea of geography. **—Karen Fleming,** Tulsa, OK

A different view

I love *Astronomy* magazine, but I find myself taking exception to "101 Must-See Cosmic Objects" (January 2022). The objects you chose are indeed some of the most stunning in the night sky. However, none of your readers will be able to look through a telescope and see the objects that fill the issue's pages; your pictures are the result of minutes or hours of data gathered from a telescope, uploaded to a computer, and combined and processed in several different programs to produce one work of art. While an experienced astronomer knows this, anyone new to the hobby will look through a telescope and be bitterly disappointed.

Your pictures are great, but if you want to give your readers a glimpse into the actual night sky, you should make some attempt to show these objects as they might actually be seen through a telescope. There is a wonder and majesty to that view. **—Miles Haanstad,** Denver, CO

Editor David J. Eicher responds:

You're correct that astroimages gather light over time and show more detail than can be seen in telescopes with the human eye. However, all of these objects are visible in backyard telescopes. One important key is to get away from city lights, to a truly dark-sky site, and to observe deep-sky objects on a moonless, dark night. Tens of thousands of observers are entranced by the fact that they can see the actual photons coming from celestial objects and striking their eyes. It's a shade too cynical to say these objects can't be seen. That's just not true.

QUANTUM **GRAVITY**

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH

SNAPSHOT

ESO/TH. STANKE & ESO/J. EMERSON/VISTA. ACKNOWLEDGMENT: CAMBRIDGE ASTRONOMICAL SURVEY UNIT. BOTTOM FROM LEFT: ESA/ATG MEDIALAB; ESA; CNSA

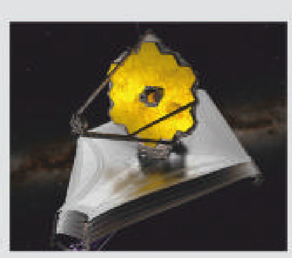
THE FLAME NEBULA BLAZES BRIGHT

A fiery tangle of glowing gas shows off its moves.

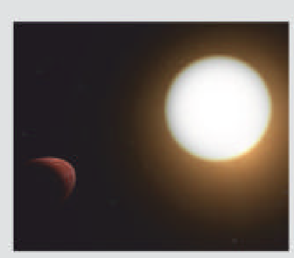
Lit by the easternmost star in Orion's Belt, NGC 2024 is also known as the Flame Nebula. The blazing emission nebula takes up the left side of this image, which combines radio observations taken with the Atacama Pathfinder Experiment's Supercam (inset rectangle with orange and red) with infrared data collected by the Visible and Infrared Survey Telescope for Astronomy (exterior, black and blue), both in Chile. Also visible are the Horsehead Nebula at upper right and the bright, round reflection nebula NGC 2023 just right of center.

The fiery colors in this image don't reflect temperature. Instead, they show the velocity of the gas in these giant clouds as the entire collection — some 1,300 to 1,600 light-years away — moves away from Earth. Redder, more distant regions are receding faster than the closer portions, which appear orange and yellow. The new radio image was taken as part of a survey of the Orion Molecular Cloud — a vast star-forming complex that includes both the Flame and Orion nebulae, plus many more. —ALISON KLESMAN

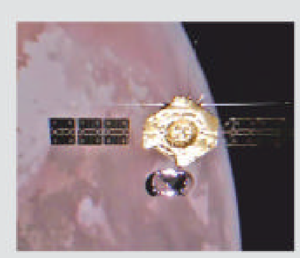
» HOT BYTES



HOME ON LAGRANGE
On Jan. 24, nearly a month after its launch, a five-minute burn successfully settled NASA's James Webb Space Telescope into its final orbit at the L2 Lagrange point.



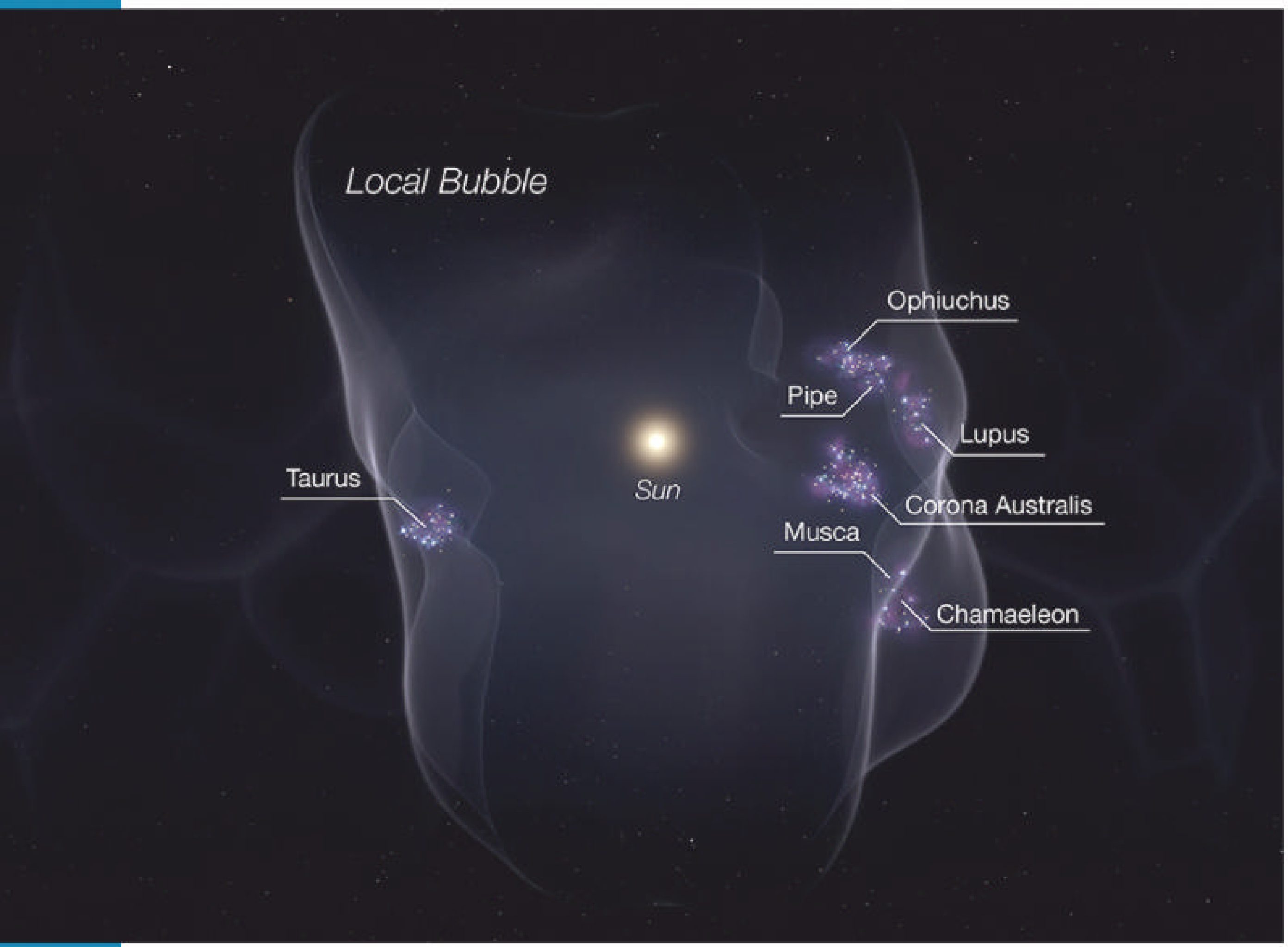
PLAY BALL
The European Characterising Exoplanets Satellite (CHEOPS) spotted a massive exoplanet whose tight orbit around its star raises tides that tug it into an oblong, football-like shape.



SPACE SELFIE
On New Year's Day, China published a first-of-its-kind photo of the Tianwen 1 orbiter above Mars, snapped by a small camera released by the craft.

A 1,000-LIGHT-YEAR-WIDE COSMIC BUBBLE SURROUNDS EARTH

This superbubble is responsible for nearly all nearby star formation.



BLOWING BUBBLES. Astronomers have found that star formation for 500 light-years around Earth is being driven by the expansion of the Local Bubble, seen in this artist's concept. CFA, LEAH HUSTAK (STSCI)

Think about bubbles, and you may think of soap or gum. But for astronomers, a bubble is something else entirely.

For example, the Sun lies within the Local Bubble — a hollowed-out region of space filled with thin, hot plasma inside a shell of cold gas and dust. For decades, the history and true size of the Local Bubble remained uncertain.

Not anymore. In a paper published Jan. 12 in *Nature*, a team led by Catherine Zucker of the Harvard-Smithsonian Center for Astrophysics outlined a kind of creation story of our stellar neighborhood: The Local Bubble is the result of a series of supernova shock waves, and on its expanding surface lie nearly all the star-forming regions near our solar system. In other words, the formation of the young stars in our galactic neighborhood were almost all triggered by the shock waves from these exploding stars, whose blown-out remains recombined to birth new suns and solar systems. Zucker calls this realization a "eureka moment."

The so-called superbubble — which is actually shaped more like a piece of pipe cutting through the plane of the Milky Way — seems to have formed 14 million years ago, propelled outward by some 15 supernovae. The last such supernova took place about 2 million years ago, according to the work.

Zucker presented her team's work Jan. 12 at an online press conference held by the American Astronomical Society. (The group was set to gather for its annual winter meeting in person in Salt Lake City, but the ongoing COVID-19 pandemic upended those plans.)

BUBBLES UPON BUBBLES

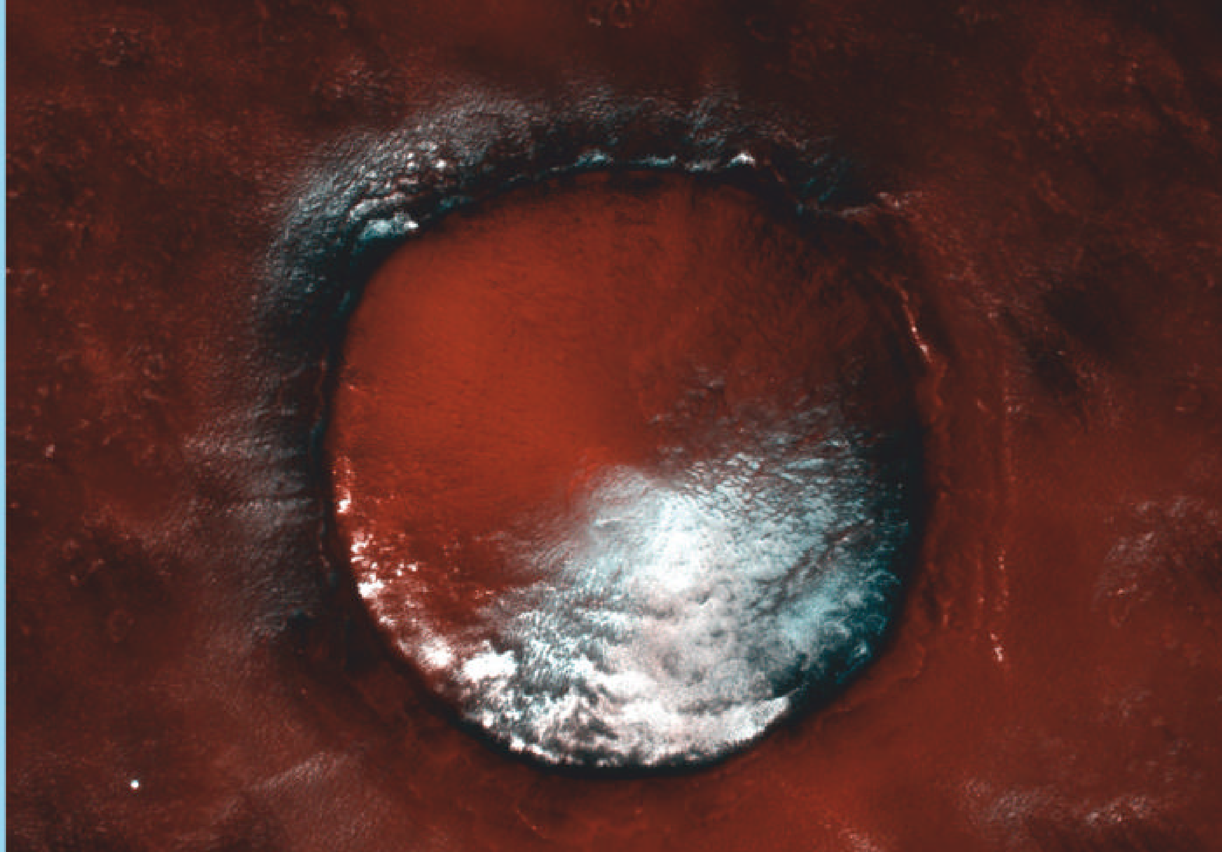
Zucker says that while there are tens of millions of stars inside the Local Bubble that predate the bubble's formation, there are thousands of young stars on its surface that have been birthed by the supernovae.

It just so happens that the Sun and our solar system currently sit inside this bubble. According to the team, the Sun rolled into the Local Bubble about 5 million years ago — and likely has sat in other bubbles at other times.

"This study is really the tip of the iceberg," says Zucker. "We have clues that not just single superbubbles but the interactions of many superbubbles are driving the formation of young stars near our Sun."

According to Zucker, the process is like plowing snow: If one or more superbubbles piles up gas in the same region of space, there should be even more star formation where those surfaces intersect.

Luckily, you don't need access to high-end data to connect to this work — you can point your telescope at those local star-forming regions. One is the Taurus Molecular Cloud — a region known to contain young stars with protoplanetary disks, which lies where the Perseus-Taurus Bubble intersects with the Local Bubble. The other is the Rho Ophiuchi complex, a vast stellar nursery in Ophiuchus. Looking into those areas gives you a chance to bear witness to the history and continuation of star birth in our galactic neighborhood. – CHRISTOPHER COKINOS



ESA/ROSCOSMOS/CASSIS, CC BY-SA 3.0 IGO

BOWL OF RUST AND ICE

Although it may not look like much, this frosty martian crater is 2.5 miles (4 kilometers) across, occupying a space over half the size of Manhattan. Oxidized red soil sits in contrast to the blue-white water ice and black basalt on the crater rim. The ice is more prevalent on north-facing ridges, which receive less sunlight throughout the year than those that face south. This image was taken by the European Space Agency and Roscosmos' ExoMars Trace Gas Orbiter (TGO) July 5, 2021, over Vastitas Borealis in Mars' north polar region. Since arriving at the Red Planet in 2016, TGO has mapped the planet's surface in search of underground ice and taken stock of its atmospheric gases. — SAMANTHA HILL

More rogue planets found wandering the galaxy

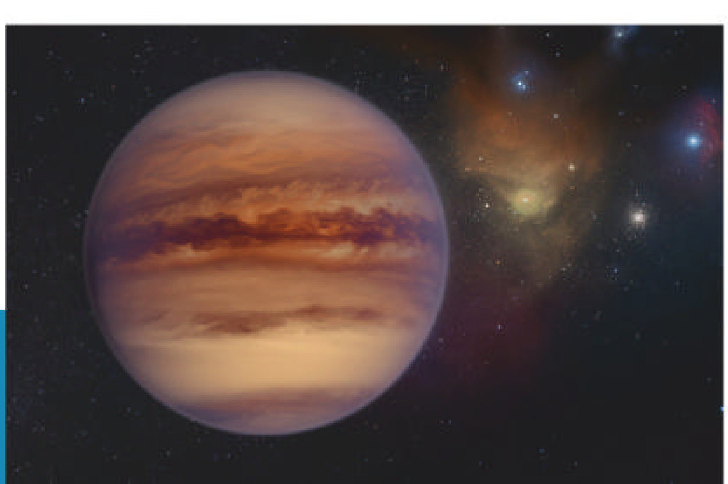
HIDDEN WORLDS are a staple of science fiction. It turns out these stories mirror reality.

Astronomers have discovered at least 70 new rogue planets within a nearby star-forming region. These elusive objects roam the galaxy and, without a sun to illuminate them, are usually too dark to image. But these particular worlds are young enough that they still radiate heat, making it possible to spot their light with large telescopes.

Still, the researchers needed to look through archival data spanning 20 years to identify the tiny motions, colors, and luminosities of these rogue worlds among tens of millions of sources. The study was published in *Nature Astronomy* in December 2021.

How exactly rogue planets form is still a bit of a mystery. As far as we know, planets only form around stars, so it's likely rogue planets were booted from their home system. But some astronomers suggest that a gas cloud too small to collapse into a star could birth a planet instead. Researchers hope these newfound worlds will provide further clues to help settle the debate.

And this group of worlds is just the beginning. According to co-author Hervé Bouy of the Laboratoire d'Astrophysique de Bordeaux in France, "there could be several billions of these free-floating giant planets" roaming the Milky Way. — CAITLYN BUONGIORNO



GALACTIC NOMADS. Researchers have spotted more than 70 new rogue planets wandering the Milky Way. ESO/M. KORNMESSER/S. GUISARD (WWW.ESO.ORG/~SGUISARD)

QUICK TAKES

SMASHING RECORDS

The Dark Energy Spectroscopic Instrument (DESI) is just seven months into a five-year mission to map the cosmos in 3D. It has already surpassed every previous 3D galaxy survey combined, cataloging more than 7.5 million galaxies.

LUNAR OCEAN

A new discovery points to Saturn's smallest moon, Mimas, as hiding an ocean beneath its ice. Previously, scientists thought the world was frozen solid, but on closer examination found it has a slight rotational wobble usually indicative of an internal ocean.

CLOSE CALLS

The Tiangong space station avoided two close encounters with SpaceX satellites, according to a Chinese document submitted to the United Nations Office for Outer Space Affairs. On both July 1 and Oct. 21, Tiangong performed evasive maneuvers to avoid a Starlink satellite.

DYING BREATH

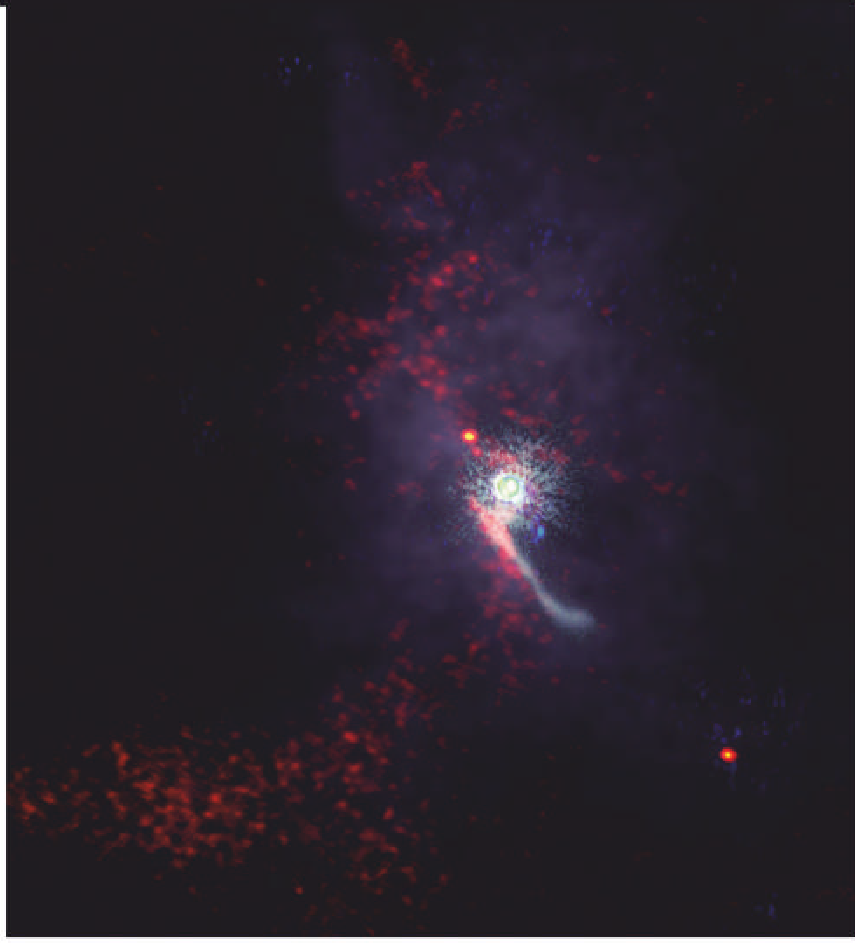
For the first time, astronomers have caught the end of a red supergiant's life in real time. The doomed star was first spotted in the summer of 2020 and was observed for its final 130 days before it exploded in a supernova.

GALACTIC WEIGH-IN

Determining the mass of the Milky Way is tricky, but it's an important number to know. Using new data from Gaia and next-generation modeling methods, astronomers are now moving our galaxy to a lower weight class: 500 billion to 800 billion solar masses.

ALIEN MOONS ABOUND?

An exomoon may have been spotted orbiting Kepler 1708 b, a Jupiter-sized planet 5,500 light-years from Earth. The large satellite is only the second to be reported — though neither it nor the first one are confirmed. — C.B.



ALMA (ESO/NAOJ/NRAO), S. DAGNELLO (NRAO/AUI/NSF), NAOJ

A stellar drive-by

MOST STARS ARE SPACED widely apart, with light-years between neighboring systems. But stars are also moving in space and brief, close encounters can occur. That's just what astronomers believe took place in the Z Canis Majoris system. Its two young stars are still forming, surrounded by an appreciable disk of dust and gas. This composite image, made with data from the Subaru Telescope, the Karl G. Jansky Very Large Array, and the Atacama Large Millimeter/submillimeter Array, shows that disk has clearly been upset, with long streams of material tugged out of place. The culprit? A stellar "intruder" that recently flew past, disrupting the swirling material. Because flybys happen quickly, cosmically speaking, it's hard to find evidence of them before it's washed away. Although flybys have previously been detected, none have been captured in such exquisite detail. The team hopes to use what they're seeing to determine how flybys impact the evolution of stars and their future planetary systems. That could lead to better understanding the events — and chance encounters — that shaped our own solar system into the place it is today. – A.K.

PLANETS MAY FORM AROUND DYING STARS

When a Sun-like star exhausts the fuel in its core, it enters its death throes and throws off its outer layers into space. This violent phase of stellar life is called the asymptotic giant branch (AGB). Despite that volatility, astronomers have suspected that under some circumstances, a new disk of material could form around the dying star, giving rise to a second generation of planets. An analysis published Feb. 1 in *Astronomy and Astrophysics* gives some of the first observational hints that this is happening.

The study focuses on 85 post-AGB stars in the Milky Way, all of which have a binary companion — and are also surrounded by vast disks of material. It appears that the second star's gravity draws back in some of the material that the post-AGB star ejected, forming a warm, glowing, rotating disk of gas and dust around the stars.

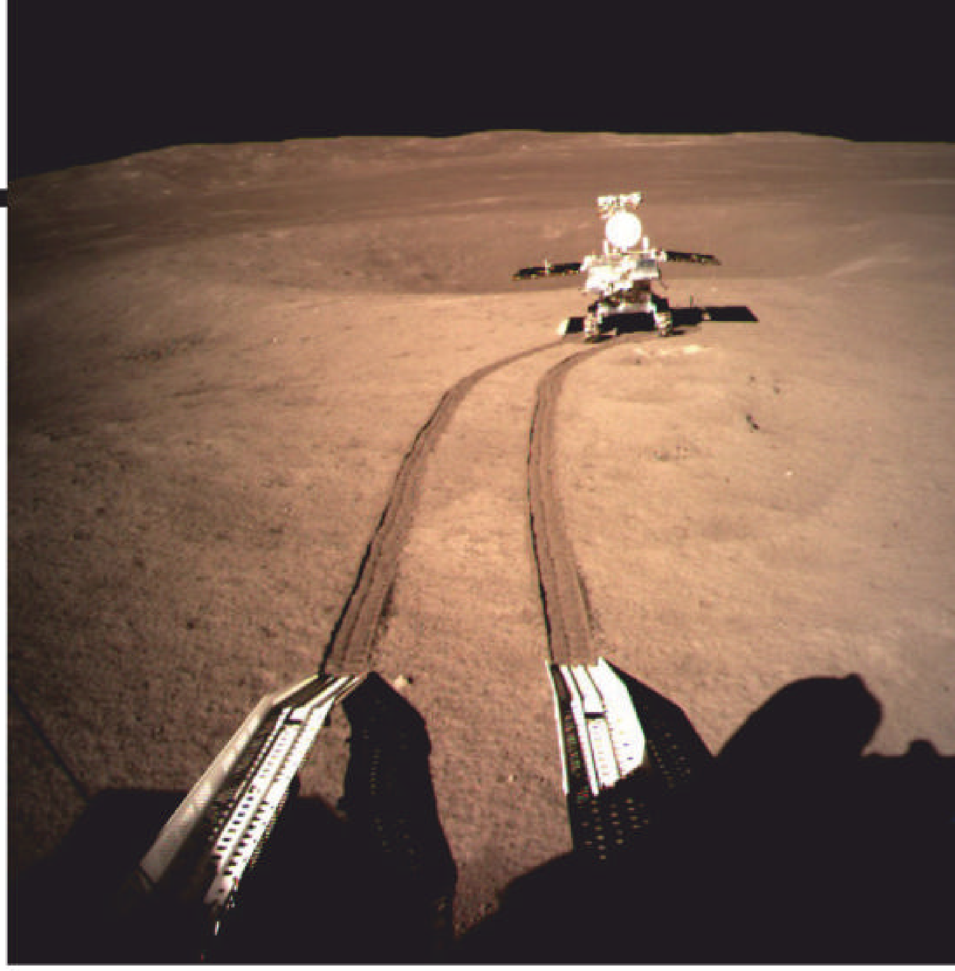
Tantalizingly, about 10 percent of these second-generation disks don't glow as brightly as expected in the infrared. Researchers call these transition disks, and they're a sign that a planet is orbiting deep within, clearing the innermost and hottest material from the disk.

The team found lower levels of dusty elements like iron on the surface of the stars themselves. This also points to an orbiting planet: Simulations show that a planet's gravity causes dust to build up just outside its orbit, preventing the dust from spiraling down onto the star.

These two factors make it "very likely" that the disks have a planet within, says the study's first author, astronomer Jacques Kluska of KU Leuven in Belgium. It's not clear whether these are first-generation or second-generation planets. Post-AGB disks last just tens of thousands of years — barely enough time to form a planet, according to current theory. This makes the team think they may be seeing surviving first-generation planets.

But the presence of a first-generation planet also creates better conditions for second-generation planets to form later: By causing dust to build up in one region of the disk, it can expedite the snowballing process of accumulating matter by which a planet takes shape. – MARK ZASTROW

A SECOND CHANCE. A transition disk (right) is an accretion disk surrounding a star that has had its inner regions carved out by a forming planet. A full accretion disk is shown at left for comparison. N. STECKI



STICKY SITUATION. Yutu-2 rolled off the Chang'e 4 lander onto the lunar surface in January 2019. CNSA

THE MOON'S STICKY SOIL

The farside of the Moon is a far different place from the nearside. It has a more rugged surface, full of craters and missing the smooth, solidified-lava oceans on the Moon's nearside. And it has a different composition, with fewer radioactive elements.

Now, you can add "stickier soil" to that list.

In a paper published Jan. 19 in *Science Robotics*, Chinese researchers gave an update on the Yutu-2 rover, which touched down on the Moon in 2019 with Chang'e 4, the first-ever mission to land on the lunar farside.

The team says that one of the most striking things Yutu-2 has encountered is how clumpy, or "cloddy," the lunar soil has been. Images taken by the Chang'e 4 lander and the rover of its wheels show that much of its fine metal mesh is covered in dirt that it has picked up as it rolled across the lunar surface.

That might seem a small detail, but it's scientifically intriguing: It stands in sharp contrast to the experience of Yutu-2's predecessor, Yutu, which landed on the nearside in 2013. Though both rovers have nearly identical designs, the original Yutu never had any large clumps of dirt gather on its wheels in more than 2.5 years of exploration — only some fine dust stuck to the metal wheels thanks to static cling.

The difference is likely related to the conditions on the lunar farside: Because volcanic activity there ceased earlier than on the nearside, the farside surface is older than the nearside. And when lunar soil — called regolith — is exposed to the harsh conditions of space for millions of years, it absorbs repeated impacts from micrometeorites, a process called space weathering. These impacting particles don't just pulverize the dirt into finer particles, they also melt them and fuse them into larger, irregular-shaped glassy globs, called agglutinates. Their irregular shapes can interlock with each other more easily, forming large clods.

Scientists should have a chance to look at the unique soil themselves in 2024, when Chang'e 6 is due to return the first-ever lunar farside samples. –M.Z.

SCIENCE: NASA, ESA, ZACHARY SCHUTTE (XGI), AMY REINES (XGI); IMAGE PROCESSING: ALYSSA PAGAN (STSCI)

A NURTURING MONSTER

As it turns out, black holes aren't always monsters. Normally, these giants lurking at the center of galaxies are known for *quenching* star formation — cutting off their host's ability to birth new stars. But the black hole at the heart of dwarf galaxy Henize 2-10 is doing the opposite: It's feeding gas into a stellar nursery located some 230 light-years away from the black hole. This is triggering the birth of new stars, according to new research published in *Nature* Jan. 19. How this is occurring is still uncertain, as normally outflows from massive black holes heat up the surrounding gas clouds so much that they are unable to cool down enough to form stars. –C.B.

1 billion

The number of seconds the Hubble Space Telescope has been operating as of Jan. 1, 2022.

FOR MASS EXTINCTION, SIZE DOESN'T MATTER

» It's a well-known story in our planet's past: A giant space rock slams into Earth, causing a catastrophe that ends in mass extinction. You might think the amount of devastation an impactor wreaks depends on its size. But new research suggests something else might matter more: The composition of the ground where that meteorite hits.

In work published Dec. 1, 2021, in *Journal of the Geological Society*, an international team of researchers examined 33 impacts over the past 600 million years. They found that whenever the rocks a meteorite struck were rich in a mineral called potassium feldspar (also referred to as K-feldspar or Kfs), the impact resulted in a mass extinction. This occurred regardless of the size of the impactor, meaning smaller meteorites striking areas rich in Kfs were more likely to cause mass extinctions than larger ones that hit regions without much Kfs.

Why might this be? Impacts throw up massive amounts of dust into the atmosphere. Called impact winter, this initially cools the planet for a year or less, but the climate quickly rights itself. The researchers propose that Kfs is the key to mass extinctions because it causes a different, longer-term effect on the climate. Kfs is a so-called ice-nucleating mineral, meaning ice tends to form around it, creating ice crystals in the atmosphere. These ice crystals make clouds more transparent and allow more sunlight through, causing Earth to warm.

EARTHLY IMPACTS. Near-Earth objects pass by our planet in this artist's rendering. ESA - P. CARRIL

Typically, a warming atmosphere melts ice crystals in clouds, reducing their transparency — blocking out sunlight and acting to balance the climate. But excess Kfs makes it harder for ice crystals in clouds to melt and can increase global warming for periods as long as 1,000 to 100,000 years. This sustained climate change has harsh consequences for life on the planet and is associated with mass extinctions.

So, when it comes to extinction-level events it appears that the mineralogy of the impact site may well matter more than the size of the impactor. —A.K.

Zodiacal light on other worlds

ONE OF THE MOST coveted sights for skygazers is the zodiacal light, a tall cone of whitish light that climbs the mid-latitude sky before dawn in autumn and at twilight in the spring. The light comes from the Sun glinting off dust particles in the solar system. This dust originates from comets and, recent work shows, possibly even from Mars.

And it turns out that anyone looking up on some exoplanets could see their own zodiacal light as well.

In research presented at a press conference held by the American Astronomical Society Jan. 13, Jian Ge of Shanghai Astronomical Observatory and the Chinese Academy of Sciences described three solar systems with debris disks that could give rise to otherworldly zodiacal light.

The team looked at three super-Earths: Kepler-69c, Kepler-1229b, and Kepler-395c, all of which lie in their host star's habitable zone. Their analysis looked for "extra" emission in the infrared portion of the spectrum, which indicates the presence of dust and debris that is absorbing light and re-radiating it at longer wavelengths.

ALIEN LIGHT. Kepler-1229b is a potentially habitable planet 2.7 times the mass of Earth. Zodiacal light might be visible from its surface as a lavalike glow in the night sky. SHAO/YUE XU

They found dust as hot as 260 degrees Fahrenheit (127 degrees Celsius). Based on the similar temperature of our own zodiacal dust, this suggests dust lurking close to at least two of the planets. It also marks the first time such disks have been found in systems with potentially habitable worlds.

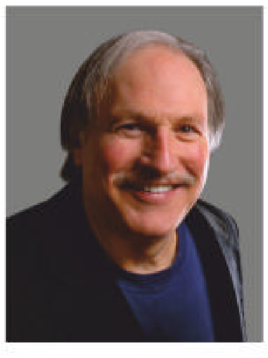
On both Kepler-1229b and Kepler-395c, red host stars would render an almost volcanic-looking zodiacal light. On Kepler-69c, the planet's venusian environment might turn its zodiacal light into a white searchlight in a dark muted sky.

The presence of dust suggests the two younger systems could still be actively forming small objects like moons and minor planets. That makes them ripe for future research into how such objects may collide and interact with exoplanets in a planetary system's early history. —C.C.

The most dangerous spectacle

Let's talk about safe solar viewing.

The Sun's purple-red chromosphere peeks out from behind the Moon in this snapshot from the July 2, 2019, total solar eclipse.
NASA/GODDARD/REBECCA ROTH



BY BOB BERMAN
Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

The next three months offer the year's shortest nights and highest-up Sun. Seems like a no-brainer: It's solar-observing time! No celestial object is easier to find or to aim a scope at. Just swivel the tube around until its shadow is perfectly round.

In the old days, budget limited my solar observing toolkit to a simple Sun filter. I'd see things like sunspots and surface granulation — happy times, augmented by being 40 years younger and accompanied by admiring girlfriends whom I suspect imagined I was a Galileo analogue (but better looking). These days, views are even more dramatic for us lucky hobbyists with H-alpha telescopes that reveal breathtaking geyserlike prominences on the Sun's limb.

So, you're set for daytime amazement. But you still have to be careful. An *Astronomy* reader wrote me a few years ago to share how one of his eyes had been ruined when he'd been too careless sweeping his telescope near the Sun, seeking Mercury. While it's widely known that staring at the Sun is hazardous, even a short accidental peek at it through a telescope or binoculars is likely to permanently destroy retina cells.

The danger ramps up during solar eclipses.

The danger ramps up during solar eclipses. My favorite totality instrument is a pair of image-stabilized binoculars. During the 2017 eclipse, my wife, Marcy, was using one. When totality was almost over, she suddenly shouted, "The right side of the Sun just turned purpley-red!"

We swiveled our heads and yelled for her to put down the binoculars, and she complied just as the diamond ring appeared. She'd saved her eyes in a close call. But what had she seen? Betcha some of you are now shouting: the chromosphere!

Yep. The same deep red that paints those prominences forms a continuous layer around the Sun, glowing in pure hydrogen-alpha. The only chance to see it naturally is during the brief seconds when the moving Moon has just finished blocking it but will momentarily expose the perilous photosphere. It's a rare celestial wonder viewable for only a mere three seconds or so. Who would take that chance? Well, Marcy did, accidentally observing the achingly beautiful phenomenon around half the Sun. I'd never seen it myself in all my totalities, starting with Virginia Beach in 1970 — until her experience motivated me to unwise heights of bravery two years later in Chile. And happily, I succeeded.

Of course, many would have dissuaded me from trying. Before the May 10, 1994, annular eclipse in Albany, New York, I warned listeners on WAMC Northeast Public Radio not to observe any part of that event without a proper filter. When we accepted on-air questions, 450,000 listeners in eight states heard one caller sincerely ask, "If the eclipse is so dangerous, why are they having it?"

True story. Anyway, with a rare U.S. totality in just two years and the year's best Sun viewing now upon us, let's talk about how to safely see the Sun. Floppy plastic filters in cardboard frames have recently become popular. They are cheap and show the Sun in a nice-looking orange hue. Their only downside is they easily scratch, leaving spots that expose the Sun's full light.

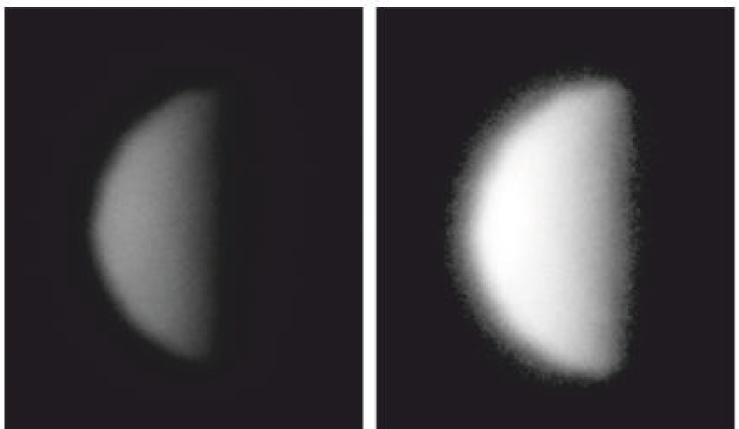
Alternatively, on the tours I've led for decades, we always supply welder's filters in shade 12, 13, or 14. They're all government certified, scratch-proof, optically excellent glass, but take heed: No lower-number shade is safe. Lately I've offered pre-eclipse tryouts. Without exception, people prefer the brighter solar image that 12s and 13s produce and find 14s unpleasantly dark. I personally have used 12s for all 10 of my eclipses, but they do deliver a slightly bright-looking Sun image. Smack dab in the middle, I've come to believe that 13s hit the sweet spot.

Since these are hardest to find, it may be smart to avoid the next eclipse rush and head soon to your local welding-supply store and order a bunch of 13 filters. What the heck — if you buy them in lightweight goggles, you can even view the Sun hands-free and attain our ultimate goal: safe, zero-effort science.

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

The shadowy Schröter effect

Venus' half phases never quite appear on time.



ABOVE: The terminator of Venus appears slightly concave, demonstrating the Schröter effect, in the image at left — a 1/160-second exposure at ISO 3200 taken Oct. 26 through the author's 3-inch Tele Vue refractor at 300x. But increasing the image levels (right) brings out more detail from the terminator shadow, giving the planet a slight gibbous phase. The effect was more pronounced visually. STEPHEN JAMES O'MEARA

CENTER: Venus shines at half phase in this image snapped by the Venus Express spacecraft. ESA/MPS/DLR/IDA, M. PÉREZ-AYÚCAR & C. WILSON

This month, I'd like to share some thoughts about a visual riddle: Why does the planet Venus appear to reach half phase earlier than predicted during eastern elongations and later than predicted during western elongations? The phenomenon has vexed planetary astronomers for centuries.

German amateur astronomer Johann Hieronymous Schröter first noticed the effect in 1793. He found the difference between the observed and calculated times of dichotomy — when the planet's disk is exactly half-illuminated — were, on average, off by six days. (Modern observations are trending toward the number of days being four.) In 1955, the late British astronomy popularizer Patrick Moore dubbed the phenomenon the Schröter effect.

Researchers still aren't sure what causes it, but explanations include optical effects like sunlight scattering off clouds high in Venus' twilight sky, and how our eyes perceive light around the terminator. Fortunately, these effects can be studied from our backyards.

An attention shift

In 2021, a waning Venus was expected to achieve dichotomy on the evening of Oct. 28.

My first observation, on Oct. 25 from Maun, Botswana, proved to be of immense interest. On that day, shortly before sunset, I began studying the planet with my 3-inch Tele Vue refractor at 300x. The expected phase of Venus was slightly gibbous at 51.8 percent, but that's not what I saw. At first, the planet's terminator appeared straight (as if at dichotomy), but slight polar "horns" or "cusps" soon became apparent, giving the terminator an imperceptible hexagonal appearance. This was the Schröter effect in action: Despite the predicted gibbous phase, it seemed the planet was already displaying the beginnings of a crescent phase. Had I walked away then, I would have thought that I had been a day too late to see dichotomy.

In effect, I had been able to do away with the Schröter effect.

However, by the onset of astronomical twilight, my attention shifted away from the planet's illuminated portion to the terminator — where, as Schröter wrote, "light and greyish shadow indistinctly intermingle." As the background sky dimmed, I could see deeper into the terminator shadow, which, in time, expanded just beyond the cusps — giving the disk a meek gibbous appearance. In effect, I had been able to do away with the Schröter effect (though it became harder to do so as the planet lowered in the sky and atmospheric aberrations confused the view).

I repeated this "attention shift" successfully Oct. 26, when Venus was 51.3 percent illuminated. On the 27th, however, the planet appeared at dichotomy, despite my efforts to see it otherwise. This wasn't surprising, as, on that date, the planet was only 0.8 percent from half phase — well within a visual margin of error with a 3-inch scope. Although the sky was cloudy on the 28th, Venus must have achieved dichotomy on prediction; the crescent phases began on the 29th, as expected.

Twilight observations

What I observed is nothing new — many sources suspect the terminator shadow plays a prime role in the phenomenon. In the autumn 2021 *Journal of the Association of Lunar and Planetary Observers*, Richard Schumde Jr. and James Dutton analyzed dichotomy measurements made between 1919 and 2001 and concluded that the Schröter effect is "primarily due to two factors: 1) twilight scattering and 2) shading near the terminator."

One reason for the time discrepancy may be that observers often determine the date of dichotomy by making daytime observations, when the brightness of the background sky helps tame Venus' brilliance. However, it also diminishes one's ability to penetrate deeply into the terminator shadow, thereby encouraging the Schröter effect.

It may be valuable to monitor the planet through early twilight instead and see if the results differ. It's important to note atmospheric conditions and other relevant details. As Schröter wrote: "These appearances depend greatly on the clearness of our atmosphere, on the telescope giving a very distinct, soft, mellow image, and on the eye being properly-prepared for such observations."

If you've had a similar experience, share it at sjomeara31@gmail.com.

BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

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THE ORIGINS OF TIME

What is time?

Why is it so different from space? And where did it come from? Scientists are still stumped by these questions — but working harder than ever to answer them.

BY STEN ODENWALD

In quantum loop theory, space is defined by a series of nodes and links that shift over time, as illustrated in this kaleidoscopic artist's concept. AEI/MILDE MARKETING/EXOZET. CLOCK: LISEYKINA/DREAMSTIME

St. Augustine said of time, "If no one asks me, I know what it is. If I wish to explain to him who asks, I don't know." Time is an elusive concept: We all experience it, and yet, the challenge of defining it has tested philosophers and scientists for millennia.

It wasn't until Albert Einstein that we developed a more sophisticated mathematical understanding of time and space that allowed physicists to probe deeper into the connections between them. In their endeavors, physicists also discovered that seeking the origin of time forces us to confront the origins of the universe itself.

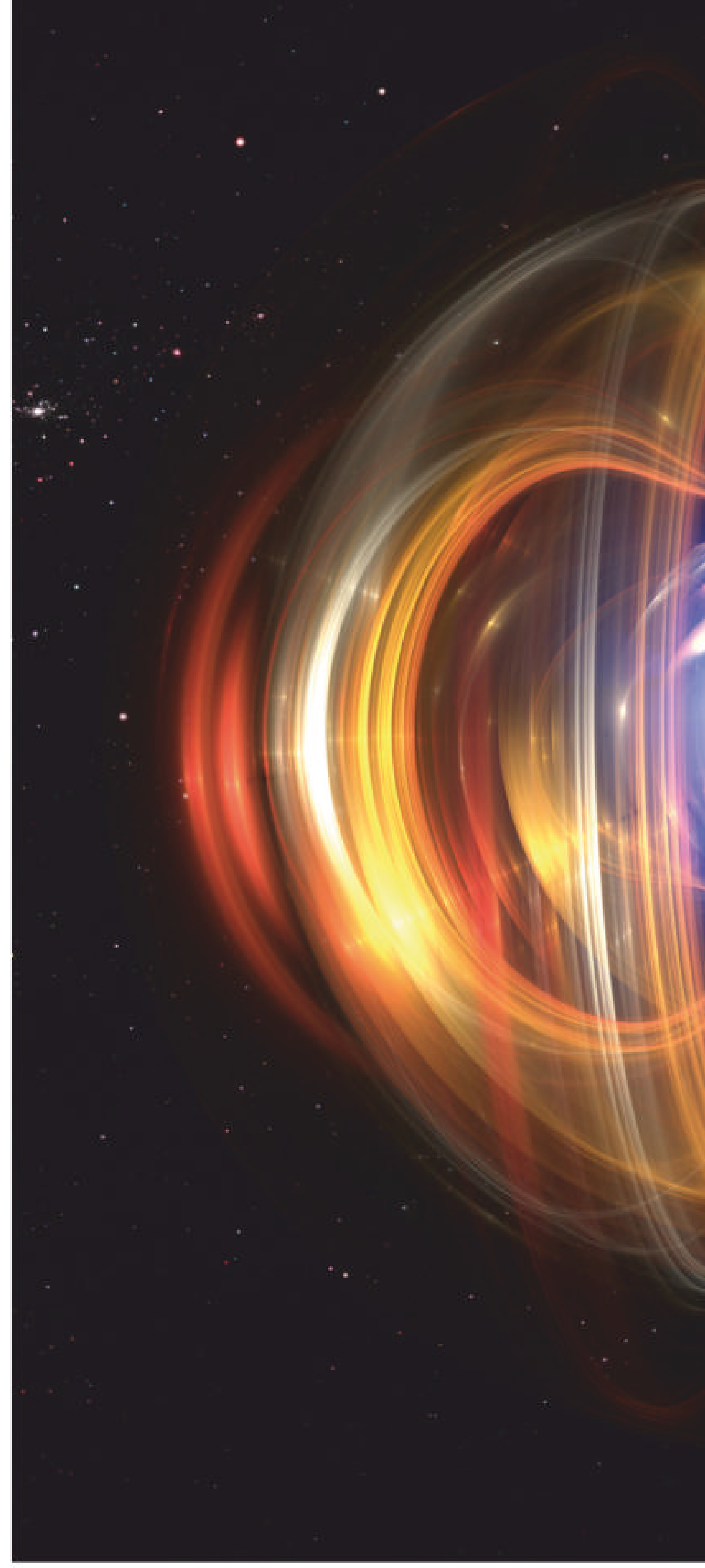
What exactly is time, and how did it come into being? Did the dimension of time exist from the moment of the Big Bang, or did time emerge as the universe evolved? Recent theories about the quantum nature of gravity provide some unique and fantastic answers to these millennia-old questions.

Our sense of time

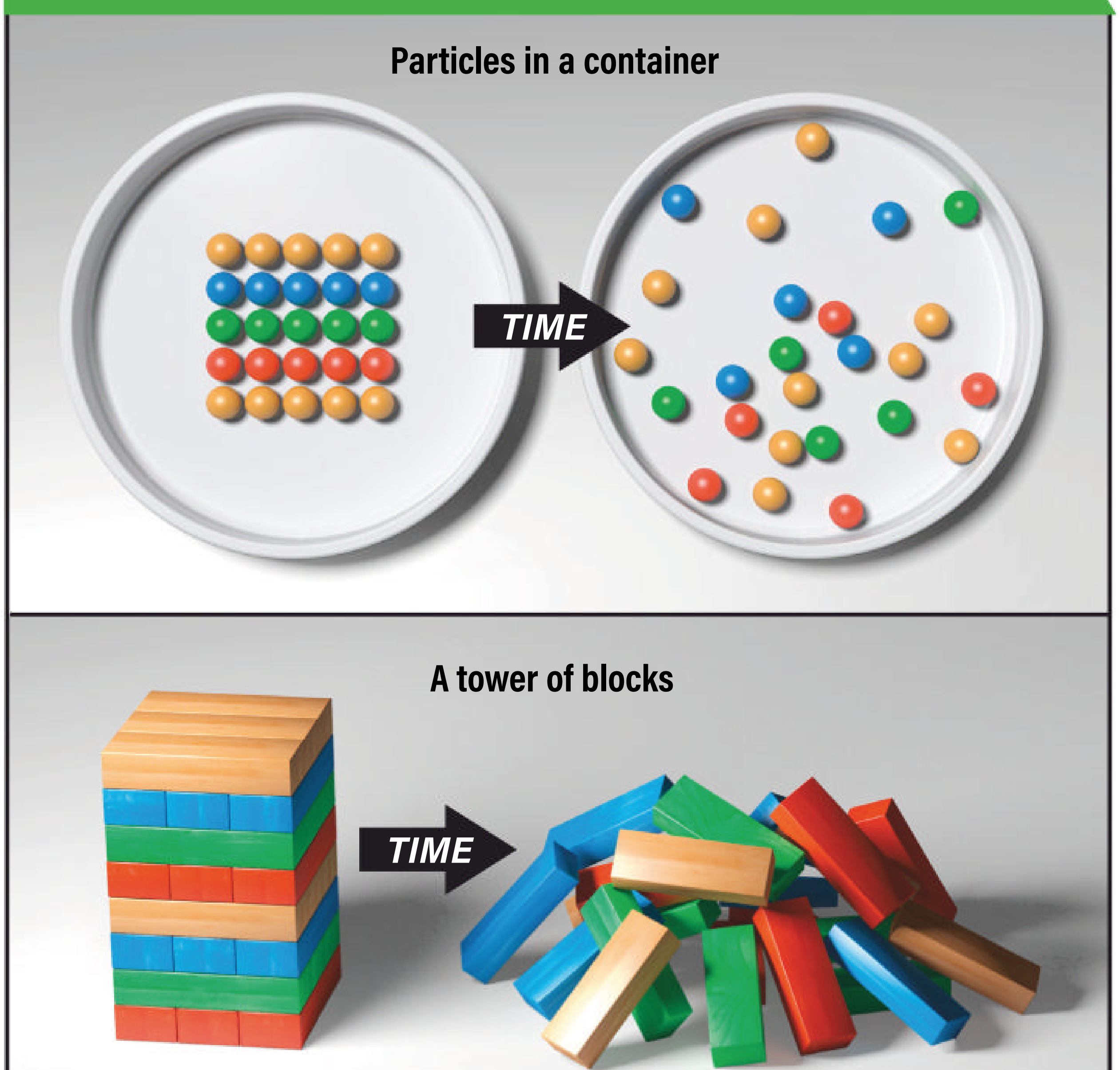
Everything you think you know about time comes largely from your internal experience of it. In terms of how your brain experiences the world, only the immediate present exists, and it encompasses only about one second.

We call this the present, but technically, it is called the experience of now by psychologists, philosophers, physicists, and brain researchers. Your brain generates your sense of the past through its stored memories and your sense of the future from predictions that it makes about what will happen in the next few seconds, minutes, or hours. The flow of time is an illusion based on a succession of immediate memories, your experience of now, and a succession of events you anticipate in the coming seconds. A century of accumulated knowledge from stroke victims and neurophysiological pathologies has also revealed the many brain systems — such as our prefrontal cortex, basal ganglia, and anterior insular cortex — that must work together to provide us with a sense of time.

We infer from past memories and our sense of how the physical world behaves that our past did indeed occur; it is not a random hallucination of unrelated snapshots. And objects exist that can corroborate aspects of this story: diaries,

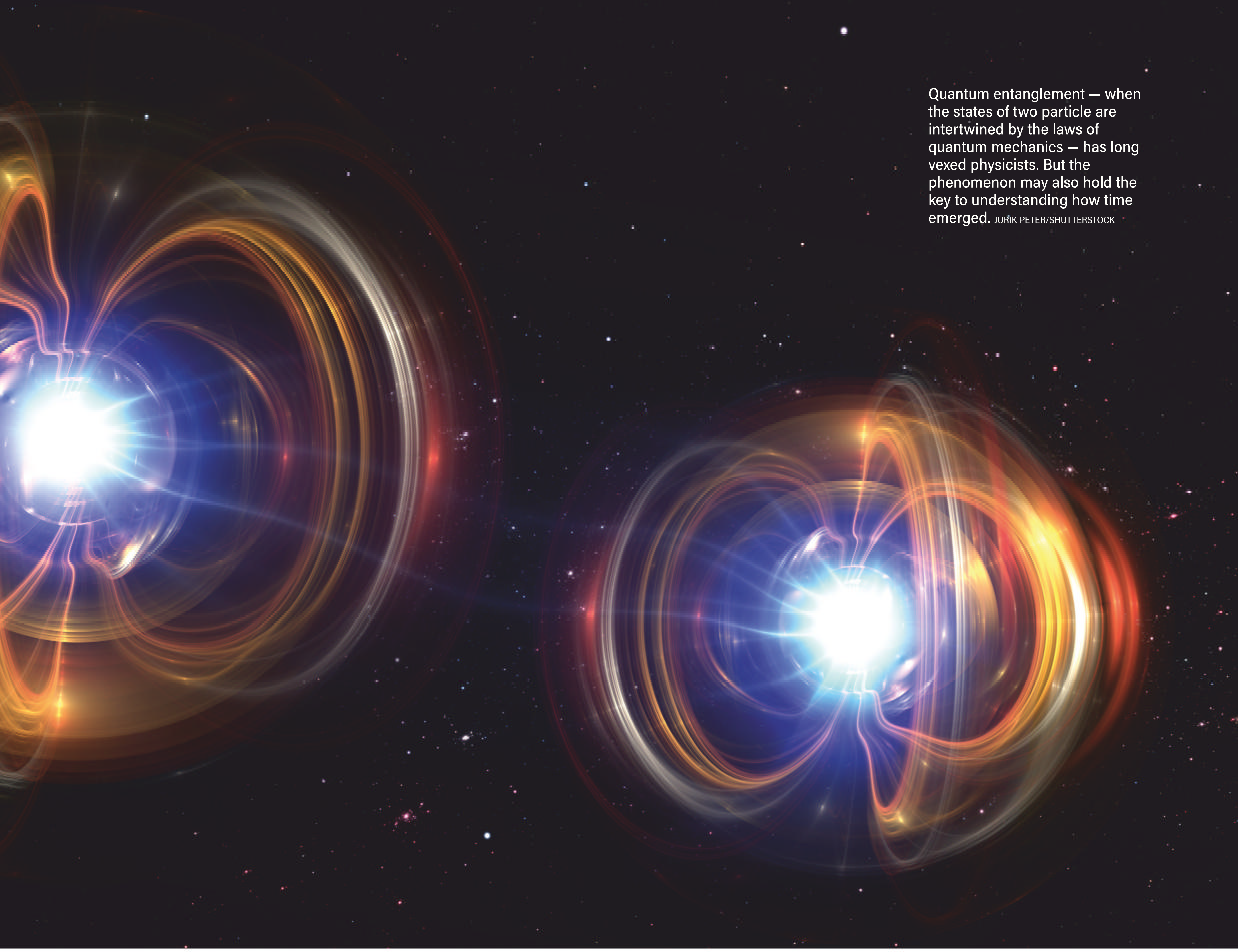


ENTROPY AND THE ARROW OF TIME



Just glancing at these diagrams makes it immediately obvious which scene came before and which one came after. That's because of entropy, which observes that the amount of disorder in the universe increases over time. Curiously, there is currently no good explanation for why entropy was lower in the past than it is now — the laws of physics describe a pile of blocks springing up to form a tower just as well as they describe a structure of blocks falling down.

ASTRONOMY: ROEN KELLY



Quantum entanglement — when the states of two particle are intertwined by the laws of quantum mechanics — has long vexed physicists. But the phenomenon may also hold the key to understanding how time emerged. JURIK PETER/SHUTTERSTOCK

photographs, video records, documents, even archaeological relics and fossils. Many of these records can be dated with independent techniques, reinforcing a self-consistent historical story.

But why do we remember the past and not the future? The reason for this asymmetry has to do with entropy — the amount of disorder in the universe. We have memories and historical records only because entropy in the past was lower than the entropy of the present.

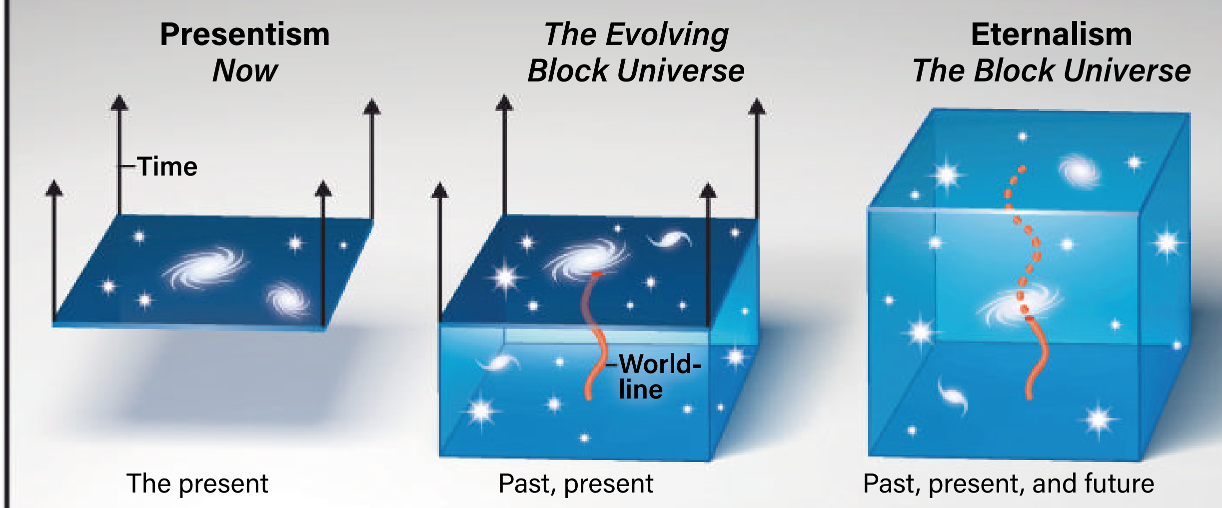
Our world features an arrow of time where entropy increases with time. This accords with our sense of time as a one-way street, from past order to future disorder. Yet, there is no basis for the arrow of time in microscopic physics — the realm of quantum mechanics. Those equations are just as valid when time runs in reverse. Therefore, some scientists think the arrow of time exists because the universe must have started out in an incredibly orderly and unlikely state. This is called the Past Hypothesis.

As systems evolve, their possible states increase as the amount of space for their states to occupy grows. Therefore, entropy increases in the universe in the same direction in time that the universe is expanding, which we experience as the arrow of time. All of our subjective experiences take place against this backdrop. In his book *The Order of Time*, physicist Carlo Rovelli at Aix-Marseille University in France notes, "In order to leave a trace, it is necessary for something to become arrested, to stop moving, and this can happen only in an irreversible process — that is to say, by degrading energy into heat." This is true when meteorites leave their impact on the ground and liberate heat, and for computer hard drives, which heat up when data is written to them. It also occurs in your brain: As Rovelli notes, every memory you have was created because it takes energy to create a memory pathway, and this recording of information both heats your brain and increases its entropy.

Time and space-time

Of course, scientists want to understand how we experience time in mathematical terms that can be tested through experiments. In relativity, the three dimensions of physical space are combined with the one dimension of time into a four-dimensional space-time. The basic elements of space-time are events and worldlines. Events are points within four-dimensional space-time at which some physical interaction or phenomenon takes

THREE METAPHYSICS OF TIME



In presentism (left), the past and future do not exist — the universe consists of only the current moment. In the Evolving Block Universe (center), the present is the boundary of space-time as it expands into the future. (The Crystallizing Block Universe is a variation of this idea that accounts for quantum mechanics.) In eternalism (right), the past, present, and future all coexist in a Block Universe.

ASTRONOMY: ROEN KELLY, AFTER STEVEN SAVITT

place, such as two particles colliding or a particle emitting a photon. Worldlines are the paths objects trace through space-time along a sequence of events.

Mathematically, we work with space-time as a four-dimensional continuum: Between any two four-dimensional points, there are an infinite number of additional points. This is a convenient approximation, but it does not represent physical space-time. There are not an infinite number of real, physical events, and so most of the mathematical points are devoid of anything physical.

This means that what we call 3D space is an illusion filled with ghostly, empty points that are not connected to anything in our real world. Einstein expressed this idea when he said, "Time and space are modes in which we think and not conditions in which we live."

As physicist Lee Smolin of the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, notes in his book *Three Roads to Quantum Gravity*, the world around us "is nothing but a network of evolving relationships. These relationships are not among things situated in space — they are among the events that make up the history of the world. The relationships define the space — not the other way around."

Relativity offers at least two views of the nature of objective reality. In one, space-time is a "block" in which the worldlines of all objects exist in their entirety. This view is called eternalism. Past, present, and future events all exist together in this so-called Block Universe, and every event is equally real. Our inability to perceive future events is an illusion. As the physicist Hermann Weyl wrote in his book *Philosophy of Mathematics and Natural Science*, "The objective world simply *is*. It does not *happen*. Only to the gaze of my consciousness crawling upward along the worldline of my body, does a section of the world come to life as a fleeting image of space which continuously changes in time."

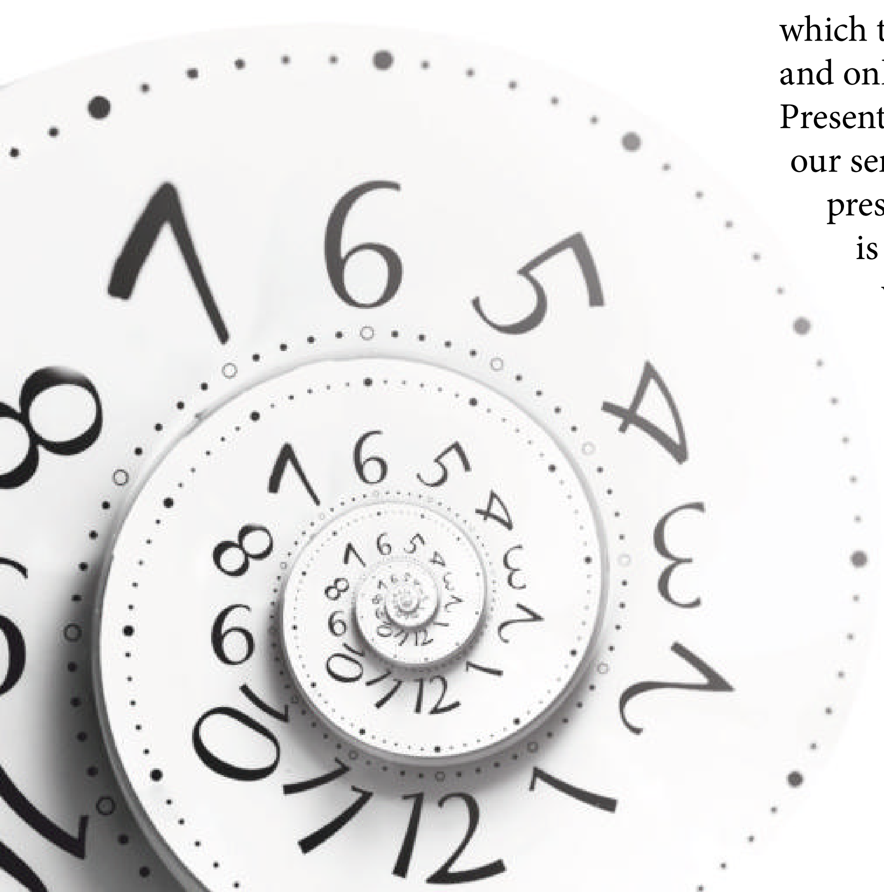
The Block Universe is a delight to time-travel enthusiasts because it says that past events still exist, and we could revisit them if we had the right technology. On the other hand, if the worldlines of every atom in your body, every electron in its orbit, and every neurotransmitter on its way to a synapse are already defined, there can be no free will.

A contrasting idea is presentism, in which the past and future do not exist and only the present has any physicality. Presentism is in far greater accord with our sense that the past is ended, the present is immediate, and the future is open and affords us some free will to choose our specific futures.

Physicist George Ellis of the University of Cape Town in South Africa and Tony Rothman of Princeton University offered an interesting combination of the ideas in 2009. They called it the Crystallizing Block Universe: The past of the current moment is fixed and stored via memories and records — in some cases, literally etched in stone. The future of the current moment is a cloud of probabilities that is determined by the laws of quantum mechanics. What we call the present is the boundary between these two regimes, where the indeterminacy of the future is crystallizing into the certainty of the past. Humans ride this boundary of crystallization through their perception of their individual nows.

This puts an end to the idea of time travel. In this view, the past exists, but as a collection of information resembling a hologram. For someone to travel into the past and encounter some object (a rock, their grandfather, etc.), they must do so along a worldline that intersects the past object. But all the worldlines constituting the object's history are already part of our past universe. Since the hypothetical time traveler's atoms and their worldlines are not a part of that known past record captured in the hologram, the time travel event did not occur! To travel into the past would be like trying to step into a hologram or embed yourself in a family photograph. The best we can do is gather all the records encoded in 3D space about a specific event or object to give us a clearer view of the past.

These discussions provide us with a way of thinking about time on the quantum, human, and cosmic scales, but do not bring us closer to the essential mystery of why space-time contains three dimensions that are purely spacelike and



exactly one dimension that is purely timelike. For this, we must understand that, through general relativity, space-time is just another way of describing the gravitational field that surrounds us. And this field, like all others, is probably subject to quantum mechanics.

Quantum gravity

The Standard Model is our fundamental theory of how three of the forces of nature — electromagnetism and the strong and weak forces — operate on a collection of 12 different matter particles (and their antimatter twins). This model describes quantum fields that exchange particles that mediate forces (bosons) between matter particles (fermions) and produce complex structures such as atoms.

The Standard Model is so successful that experiments at the Large Hadron Collider at CERN, operating at energies up to 14,000 GeV, have been unable to find any significant deviations from calculated predictions. But we know that the Standard Model is incomplete because it has no room for several phenomena we observe. These are dark matter, the invisible stuff that glues galaxies together; dark energy, the mysterious repulsive energy driving the ever-faster expansion of the universe; and any mechanism to explain either cosmological inflation, the exponential expansion of the universe in its early stages, or the fact that we live in a universe dominated by matter instead of equal amounts of matter and antimatter.

The Standard Model also has no explanation for gravity, the fourth fundamental force. That's because gravity — in the guise of space-time — actually provides the 4-dimensional coordinate basis for all of the Standard Model fields. Ultimately, we need a quantum theory of gravity that leads to a space-time that looks like ours as described by general relativity, but at the same time explains how the Standard Model arose. The theory should also explain dark matter, dark energy, inflation, and the abundance of matter over antimatter, just for starters.

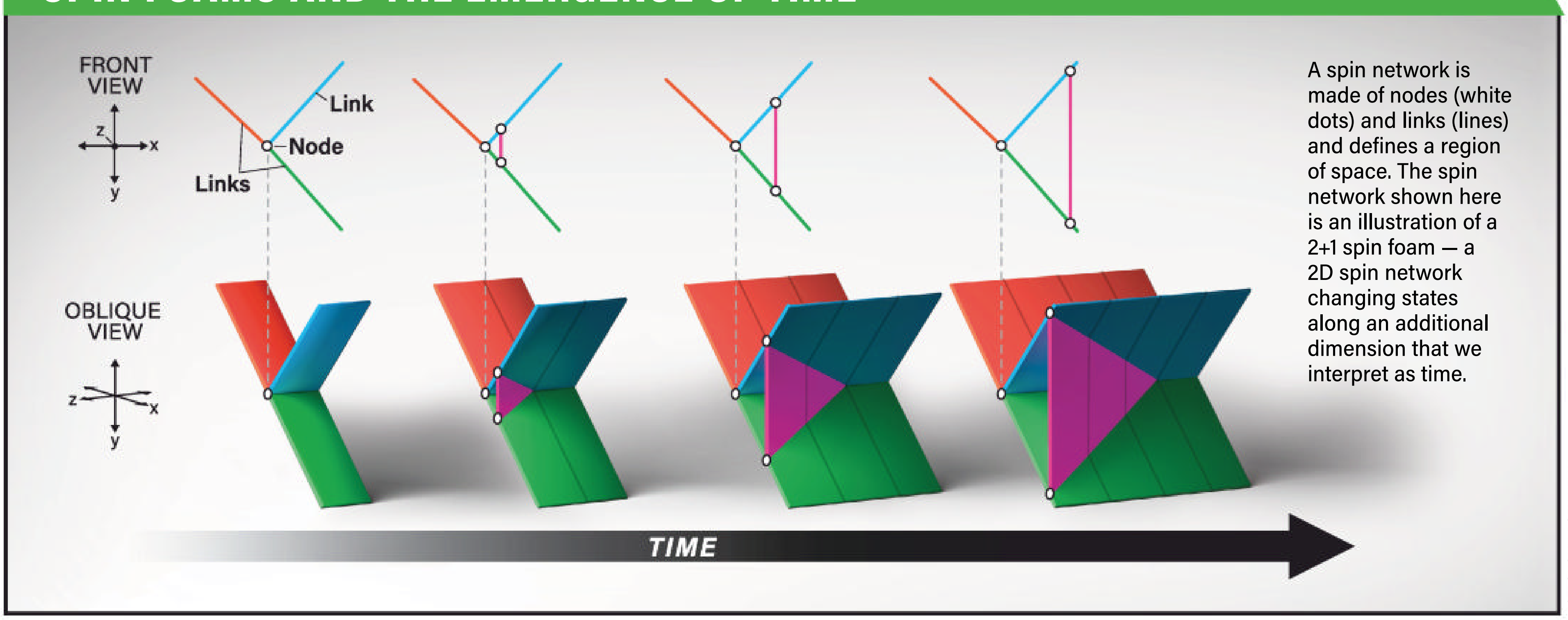
String theory, developed in the 1980s by John Schwartz at Caltech, Michael Green at Queen Mary University of London, and others, is one attempt. It describes the particles and fields of the Standard Model as 1D loops of energy that move and vibrate in an 11-dimensional space-time. The problem is that string theory depends on the pre-existence of a flat four-dimensional space-time through which the strings move. This means gravitons — the hypothetical particles that transmit the force of gravity — can only interact very weakly with space-time. String theory cannot yet derive the existence of space-time itself from the quantum comings-and-goings of gravitons. It also has no ability to provide insight as to the nature of time.

For this, we must look beyond string theory. One such possibility that has generated a lot of interest in the last 30 years is called loop quantum gravity (LQG).

Developed in the 1990s by Smolin and Rovelli, among others, LQG proposes that space consists of objects called nodes that have Planck-scale volumes of 10^{-99} cm^3 — the smallest scale that physics can account for. These nodes define where three-dimensional space exists. The nodes are connected to each other by links, like a set of Tinkertoys. Networks of these nodes and links are called spin networks. But spin networks can be altered in sequences that add and subtract links and nodes. These changes form a 4-dimensional network called a spin foam. (For more on string theory and LQG, see "Imagining our infant universe" in the April 2022 issue.)

What we call the present is the boundary between these two regimes, where the indeterminacy of the future is crystallizing into the certainty of the past.

SPIN FOAMS AND THE EMERGENCE OF TIME



A spin network is made of nodes (white dots) and links (lines) and defines a region of space. The spin network shown here is an illustration of a 2+1 spin foam — a 2D spin network changing states along an additional dimension that we interpret as time.

ASTRONOMY: ROEN KELLY

This spin foam is a 3+1-dimensional structure, where the 1 represents the direction along which the changes between spin networks occur. What is remarkable about spin foams is that although they seem to be purely spatial, a phenomenon that we recognize as time emerges from the successive changes in these networks.

The justification for interpreting this axis of change as time has to do with one of the most important features of relativity, called causality. This principle holds that effects must come *after* their causes in space-time, which allows us to connect events together in a logical timeline.

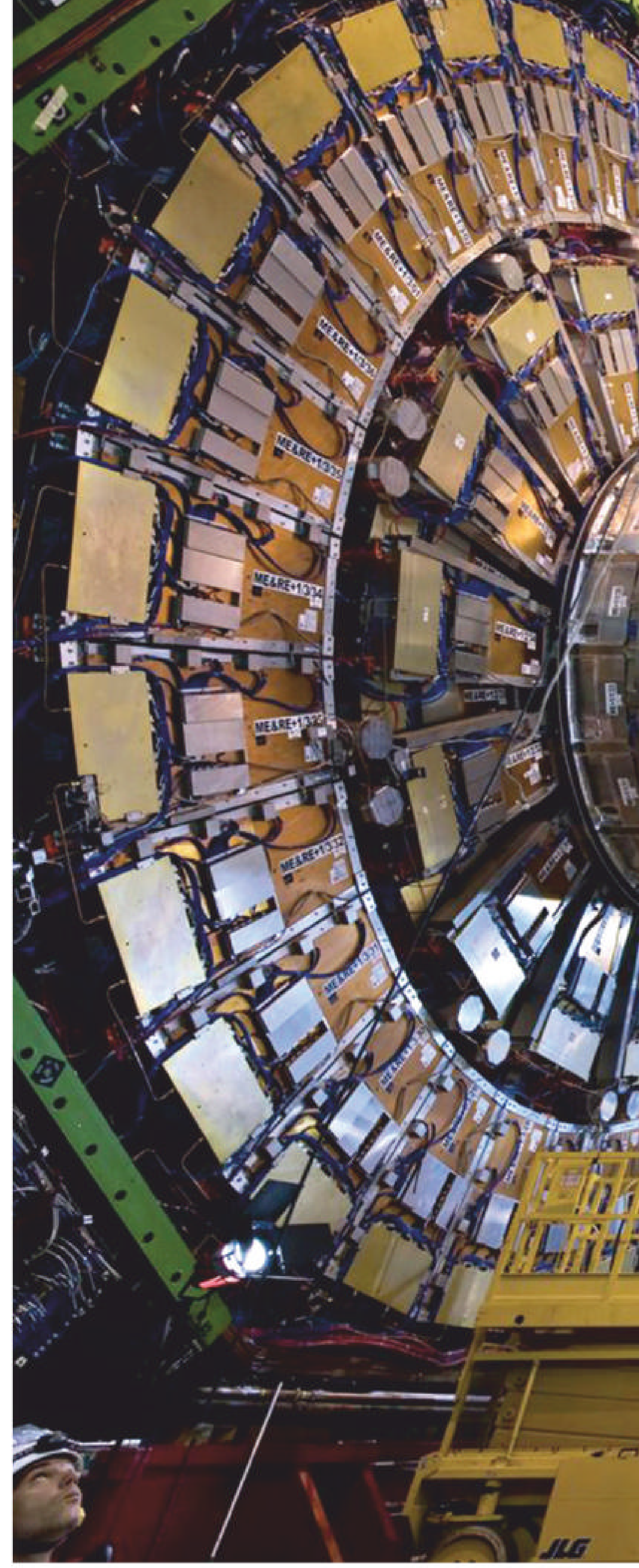
Think about a drawing of your family tree. The lines you draw between your grandparents, your parents, and yourself are meant to be indications of cause and effect, not physical lines in space. But they do form a very crude timeline. Similarly, causality lets us assign changes in a spin foam to sequences that we interpret as space unfolding over time.

Embedded in each spin network is a small collection of nodes and links that can serve as a clock for that network — like a timestamp in a photograph. But just as a timestamp does not exist outside of a photograph, the concept of time can only exist within the spin networks.

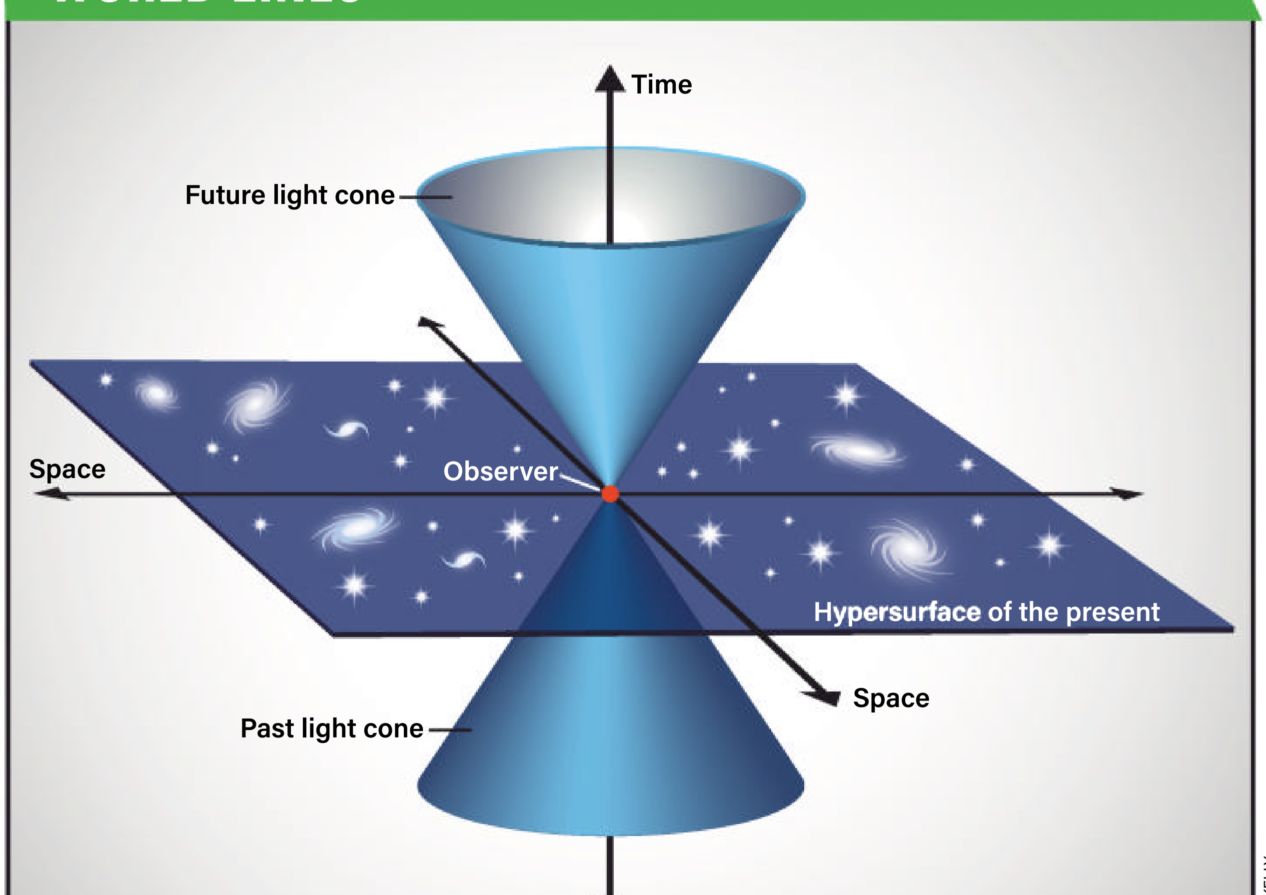
The emergence of time

This idea that time is an emergent phenomenon from within our space-time and not present outside of it was proposed in 1983 by physicists Don Page of the University of Alberta in Edmonton and William Wootters of Williams College in Williamstown, Massachusetts. It was a dramatic solution to the origin of time, placing its source in a phenomenon called quantum entanglement.

In quantum mechanics, two particles are entangled if they interact with each other in such a way that their quantum states can no longer be described independently: That is, if you measure the quantum state of one particle, causing its fuzzy cloud of possible states to collapse to one single state, you can immediately deduce the quantum state of its partner particle. The wave function of the partner particle also collapses instantly, even if it has since zipped off to the other side of the universe. Einstein hated this because it violates the principle of causality in relativity — another way in which quantum mechanics and relativity don't mix.



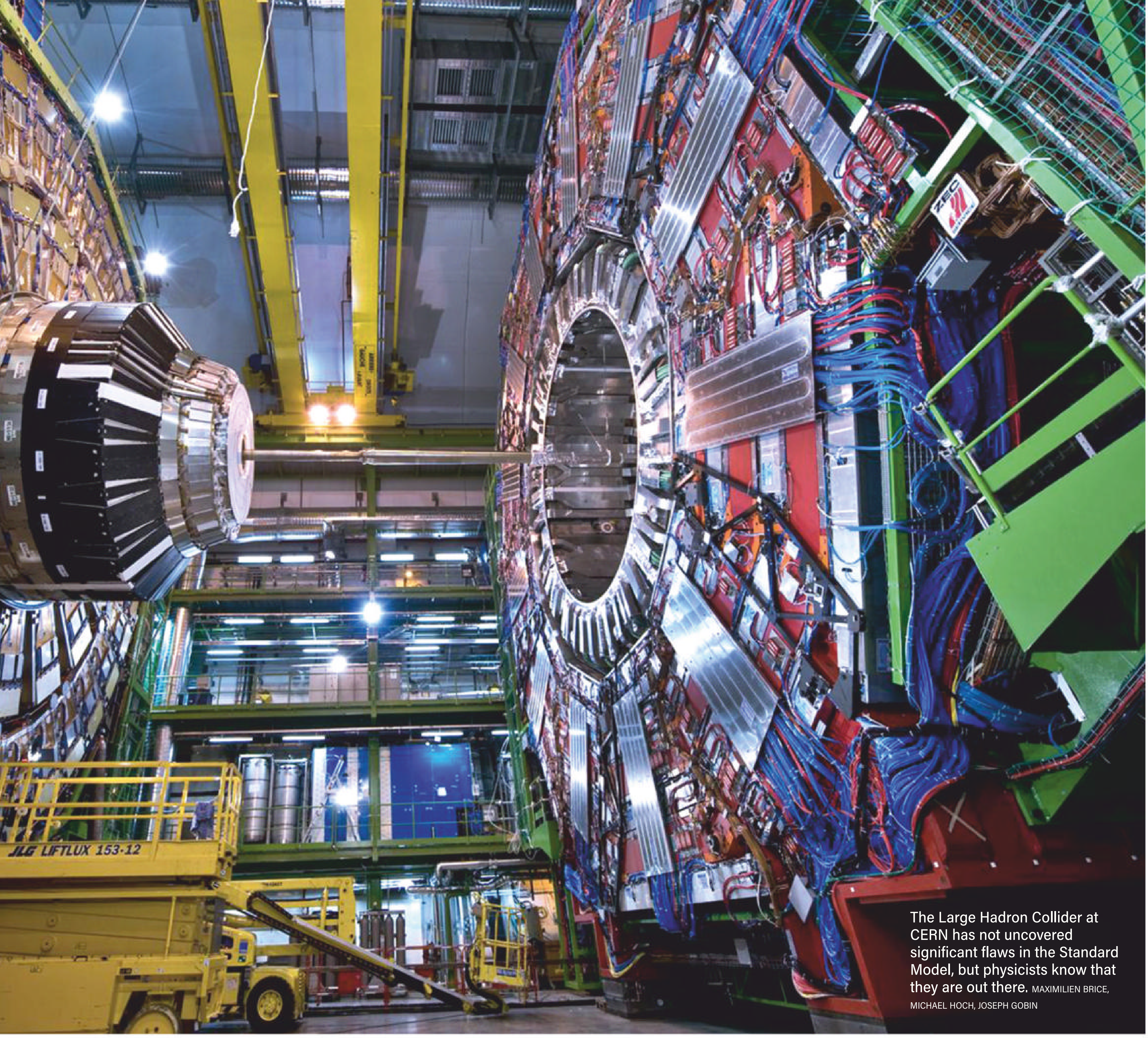
WORLD LINES



The paths that a particle can take through space-time are limited to their light cones — the path through empty space that a photon would take, the speediest possible path through space.

ASTRONOMY: ROEN KELLY

But Page and Wootters suggested that an entangled system could give rise to the phenomenon of time — and recently, scientists have begun to test this hypothesis in the lab. In 2013, experiments led by physicist Ekaterina Moreva at the Istituto Nazionale di Ricerca Metrologica in Torino, Italy, showed that the emergence of time occurs in a system of two entangled photons. If an observer uses one photon as a reference clock — or timestamp — to observe its entangled partner, the system appears to evolve in time. But to an observer comparing the entangled photons to the rest of the universe, the system remains static. This means time only emerges for observers within the



The Large Hadron Collider at CERN has not uncovered significant flaws in the Standard Model, but physicists know that they are out there. MAXIMILIEN BRICE, MICHAEL HOCH, JOSEPH GOBIN

universe — there can be no "outside the universe" clock where time exists.

Related to this idea of quantum entanglement is the no-boundary proposal for the origin of the Big Bang, developed by James Hartle at the University of California, Santa Barbara, and the late Stephen Hawking, as well as independently by Alexander Vilenkin at Tufts University. In 1983, they proposed that one of the universe's four spacelike dimensions underwent quantum mechanical tunneling into a timelike dimension at the Big Bang. This triggered what Vilenkin calls "eternal inflation." Although the universe initially was made of pure space in many dimensions, once one dimension emerged as the direction of a past-to-future succession of states, the Big Bang occurred. This triggered the progression of the universe in the direction of increasing entropy, defining the arrow of time — a critical transition. According to Smolin, without it there could be no coherent 3+1 space-time, but simply a random collection of 4D spacelike spin foams that do not lead to our physical space-time.

The bottom line

Our experience of time may be subjective and limited to a sense of now, but on the cosmic scale, time seems to be a feature of entangled relationships between objects and not a feature from outside our universe. The arrow of time is a consequence of the increasing entropy of an expanding universe since the Big Bang. It appears this precludes us from remembering the future. But at least we have our memories, courtesy of the steady march of entropy, which allows us to recover past events and stitch them into a consistent story. Lucky for us, our universe seems to have a consistent story to tell in the first place!

Sten Odenwald *is an infrared astronomer who worked on the Cosmic Background Explorer. He religiously keeps up with early universe theory.*

ECLIP
AT THE BOTTOM OF

Astronomy's intrepid travelers journeyed to Antarctica to witness one of nature's grandest spectacles.

BY DAVID J. EICHER

"It's going to be like going to another planet."

Every one of my friends who had been to Antarctica said this same thing. And it was true. In December, I found myself, along with a group of about 50 astronomy enthusiasts, at the frozen base of the world chasing a total solar eclipse.

Our group descended on Union Glacier Camp, a spot between the Antarctic coast and the South Pole, located in the thin path

SE THE WORLD

The Dec. 4, 2021, total solar eclipse was visible from Union Glacier Camp, Antarctica, with Mercury near the Sun and Venus to the right. PHOTO: DAVID J. EICHER. MAP: *ASTRONOMY*: ROEN KELLY

of totality for Dec. 4's big event. The trip was unlike any I had experienced before: chilling to the bone, yes, but also full of wonder for the sky, the solar system, and the icy wilderness of one of the most remote areas of our planet.

Traveling anywhere in the world of lingering COVID-19 is tricky, and this jaunt was especially rife with paperwork, daily PCR tests, and all manner of preparatory hoops to jump through, mostly to satisfy the Chilean government. We traveled to Santiago and then on down to Punta Arenas — more or less the southern edge of civilization — before setting off for the seventh continent. The journey was a long one, coordinated by *Astronomy*'s travel partner, TravelQuest International, and led by the energetic Cody Carter and Michel Girardin.

Several trips ferrying astronomy enthusiasts to see the eclipse by ship unfortunately ran into trouble due to positive COVID-19 tests on board. We heard of

A bright flash of sunlight shoots through valleys on the edge of the Moon in this totality shot taken from Union Glacier Camp.
WIJAYA SUKWANTO

two such trips that were scrubbed. Our approach was different: Only in the last few years has a travel company arranged to land a Boeing 757 on the blue-ice runway at Union Glacier Camp. And that's what we did, touching down right on the glacier. We were not only tested every day (and before leaving for Chile at the trip's beginning), but also on the plane and after arrival. We subsequently learned that a single positive result would have canceled the trip for all parties.

Onto the ice

We landed on the ice on Monday, Nov. 29, with eclipse day, Dec. 4, a ways off. This time of year is summertime in the Southern Hemisphere, so temperatures were as mild as one could dream of in such a place. Nonetheless, it was cold. The highs during the day typically ranged between 0 degrees Fahrenheit (–18 degrees Celsius) and 20 F (–7 C), and the sunshine was constant. The only darkness we would see from the ice would be during the eclipse itself.

Requirements for Antarctic travel are firm. One needs a whole wardrobe of gear and must don multiple layers of clothing at all times. Aside from already cold air temperatures, the wind chill could make it feel vastly colder, especially on expeditions that ventured away from the relatively placid camp. Thermal underwear, three pants, fleece layers, multiple glove and hat options, a heavy down polar overcoat, buffs to cover the face, heavy polar boots, and a thermal, insulated, two-layer sleeping bag were all necessary. We slept in two-person tents warmed a bit by solar radiation, but comfy sleep required tucking in snugly with just mouth and nose exposed.

The flight from Punta Arenas to Union Glacier Camp was a four-hour trek, seemingly quick compared with the flights from the U.S. down to Chile. And as we approached Antarctica, our first glimpses of the continent were exhilarating. We spied large mountains heavily dusted in snow along the coast, giving us chills in anticipation of what was to come.

Landing a fully loaded 757 on a miles-long blue-ice runway was an interesting experience. As we approached Union Glacier Camp and lost altitude, the plane set down gently and rolled along, and we continued slowing for a long time as the thrust reversers deployed. Eventually we rolled to a stop and prepared to deplane with all our heavy gear on. The first moments in Antarctica were very chilling; a significant wind greeted us as we deplaned. And the runway ice was extremely slick — care had to be taken with steps, even in our heavy polar boots.

We piled into trucks for the short journey to the camp itself. The vehicles were vanlike but fitted with oversize, heavy tires, or tracked vehicles. Driving in Antarctica requires caution: The pathways are clearly marked with flags, as only certain routes have been explored with radar to ensure crevasses do not lurk under the surface.

The camp itself was relatively nice, considering our remote location. A tour enabled us to pile equipment into our tents, and see the common buildings and the toilet and shower facilities. The common buildings included a Quonset hut used as a dining facility and kitchen, with strictly adhered-to meal times, and another containing a library that was also used for

I stopped for a selfie on my first Antarctic expedition, near Union Glacier Camp. DAVID J. EICHER

We spied large mountains heavily dusted in snow along the coast, giving us chills in anticipation of what was to come.

talks. Hygiene was carefully planned: the rule was a shower only every second or third day, and on expeditions, one had to cart a pee bottle along in case deposits had to be made along the way.

The moment of mid-totality, photographed from the Union Glacier Camp observing site, shows a magnificent and round corona. WIJAYA SUKWANTO

Adventures in Antarctica

What do astronomers do in a perpetually illuminated landscape for several days before a big eclipse event? Explore, explore, explore, of course. In Punta Arenas, we had stayed in a hotel steps from the past adventures of Robert Scott, Roald Amundsen, Ernest Shackleton, and other explorers. Now we could go on our own version of their journeys.

Generally speaking, on our adventures away from camp, temperatures were colder and winds much stronger than we had at home. Thus, we had to be dressed in the heaviest combination of clothes we'd brought. The temps hovered around 0 to –5 F (–17 to –21 C) or a little colder, and with stiff winds, the chill could be down to –30 F (–35 C) or –40 F (–40 C).

So, bundled up, on the first whole day on the ice, we headed off to see the Drake Icefall. The sky above us was clear as a bell

So, bundled up, on the first whole day on the ice, we headed off to see the Drake Icefall. The sky above us was clear as a bell and we trucked some 45 minutes to get to the site.

as we trucked some 45 minutes to get to the site. Distances in Antarctica are very deceiving. The atmosphere is so clear and the lines of sight so good that you can see a mountain 10 miles (16 kilometers) away and it looks like you could just walk right over to it. The Drake Icefall is a huge cliff of ice about 2.5 miles (4 km) wide that rolls off a height and helps to feed the slow movement of Union Glacier. It is in the Heritage Range of mountains, forming part of the Ellsworth Mountains. We hiked about an hour, assisted by tiny crampons called "microspikes," and a ski pole for extra stability.

Expeditions over the following days took us to a variety of Antarctic locations, showing us the kinds of mountains, ice pools, glacial features, and rocks that lie scattered over the region of our camp. We next ventured to the Charles Peak Windscoop, which, as its name suggests, helps to funnel energy into the glacier, and is a treasure trove of geological features. The complex overlain terrain showed us not only blue-ice glaciers, but melt ponds, moraines, sloped mountains, and hard snowpack. Wind erosion plays interesting tricks with the surfaces, creating a dimpled ice surface to walk on, again requiring microspikes and care to navigate.

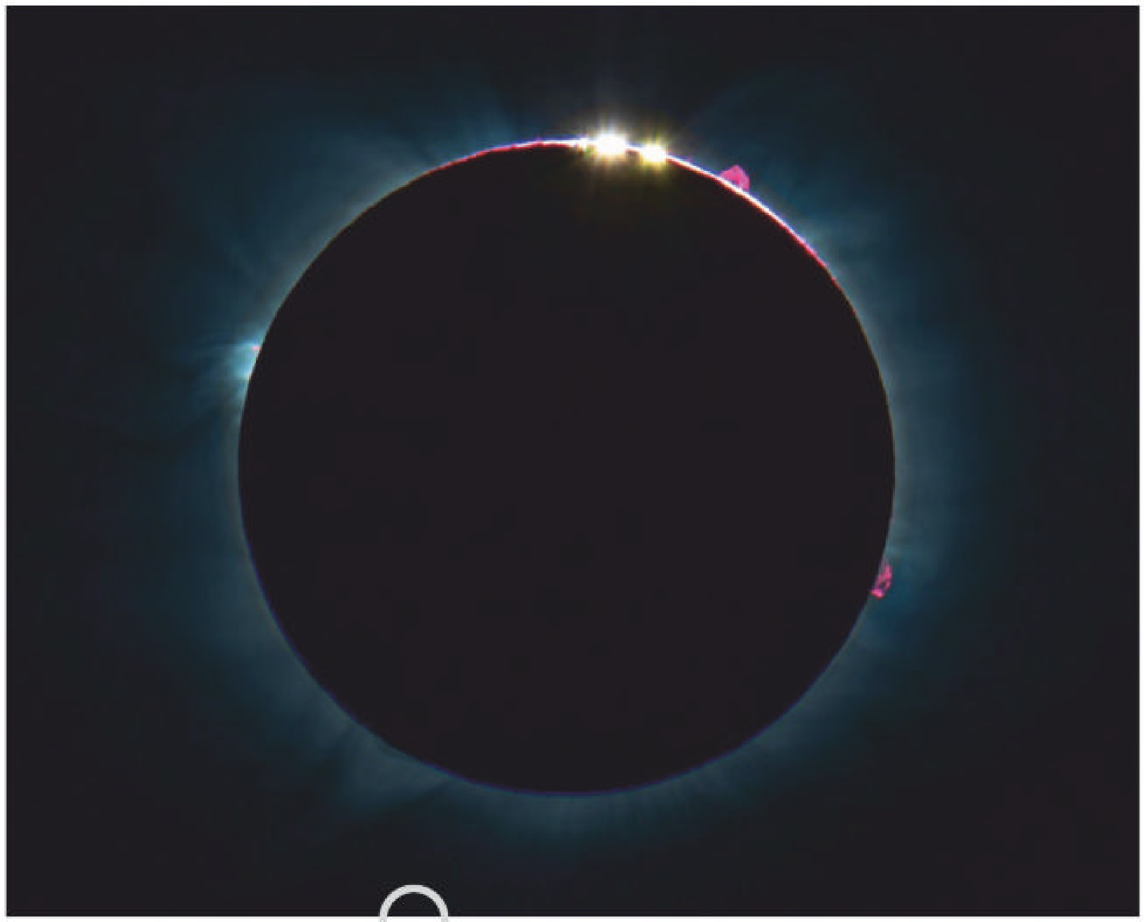
The typical experience of walking across Union Glacier: We had to use microspikes on our boots to make it along the ice, which could be very slippery otherwise. DAVID J. EICHER

Subsequent excursions provided some higher elevation climbs, areas of concentrated rocks, and more. The next day carried us to one of the most absorbing areas, Rhodes Bluff. This bare rock bluff stands 2 miles (3.2 km) northwest of Mount Dolence and offered an area where we could walk along and examine zillions of fragments of metamorphic and sedimentary rocks, including some fossils. The day was cloudy, solidly so for the first time since we had landed, and this pumped up our blood pressure. We were now two days from the eclipse.

The day before the eclipse, I delivered a lecture on what to expect during the event. We also visited the Buchanan Hills. This cluster of mounds north of Union Glacier gave us a rugged test. Facing incredible cold and wind, we marched along a raised ridge

TOP: Our trip to the Buchanan Hills was the coldest and windiest day in Antarctica, with wind chills up to –30 F (–35 C). Over the rock ledge in the center of this image was a huge drop-off and ice fall — and "if you go over that lip, you will slide down a mile and be dead," said the guides. We had to walk carefully on that day. DAVID J. EICHER

ABOVE: Our Antarctic two-person tent, which I shared with Michel Girardin, one of TravelQuest's guides, is seen here. The temperature range at camp was surprisingly warm, between about 0 F (–18 C) and 20 F (–7 C) for highs on many days — though sometimes down to –5 F (–21 C). The wind chill brought temps down to feeling like –20 F (–29 C) or –30 F (–35 C). But the Sun heated this tent to create a remarkably comfortable atmosphere much of the time. DAVID J. EICHER



ABOVE: A shot taken just after the start of totality shows remnants of the diamond ring effect and a reddish loop prominence. WIJAYA SUKWANTO

BELOW: Following the eclipse, *Astronomy*'s travelers took this group shot to remember the expedition. DAVID J. EICHER

and were told by the guides that if we went over the ridge, down onto the glacier, we would certainly be killed. Thankfully none of us did, and we imagined the high altitude paired with bitter cold and wind approximated what one might find at base camp at Everest.

Eclipse day

First contact would occur at 3:53 A.M. on Saturday, Dec. 4, and so we set alarms to get up at 1:30 A.M. We awoke to an

It was a perfect view of the eclipse. The sky remained fairly light, with a flash of thin, reddish chromosphere ringing the Sun and a smallish, circular corona.

At Charles Peak Windscoop, incredible formations of sedimentary rock displayed monumental banding on the mountains. Scenes like this created an otherworldly view of our own planet. DAVID J. EICHER

enormous sense of relief: Gone were the clouds, and we had an azure-blue sky all the way to the horizon. We gathered equipment and piled into trucks, traveling about 2 miles (3.2 km) to the eclipse-observing site. It was cold that morning, about 2 F (–17 C), and windy, which made the pre-eclipse viewing slightly challenging. Thankfully we had a temporary building at the site with warm beverages. But we had already won the day — a photometrically clear sky horizon to horizon.

First contact always conveys a bit of magic. Even experienced eclipse chasers seem swayed by the alignment of Moon, Sun, and Earth, as the first bite is taken out of the Sun's disk. The partial phase went on for nearly an hour, until suddenly, we had a nice diamond ring flash and the beginning of totality.

It was a perfect view of the eclipse. The sky remained fairly light, with a flash of thin, reddish chromosphere ringing the Sun and a smallish, circular corona. As with every eclipse, totality seemed emblazoned on the mind but went quickly, a literal 46 seconds from our site. Mercury appeared like a tiny gem near the Sun and Venus was brilliant farther down the ecliptic, but the relatively bright eclipsed sky revealed only a small number of stars.

After totality, the celebration began in earnest. Our group had traveled to the bottom of the planet, gone through unprecedented restrictions, tests, and trials to be there, and conquered. An ecstatic crowd relished the experience, happy in the success they tasted and looking forward to the big American eclipse of 2024 and beyond.

David J. Eicher *is editor of* Astronomy *and the author of 26 books on science and history, the most recent being* Cosmic Clouds 3-D *with co-author Brian May.*

The partial phases of the eclipse led up to a very exciting totality as the Moon inched across the Sun's face. WIJAYA SUKWANTO

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

This stunning trick of perspective makes it look as if the European Southern Observatory's Very Large Telescope is shouldering the weight of Earth's eclipsed satellite. A longer-than-usual total lunar eclipse will delight skywatchers this month. Y. BELETSKY (LCO)/ESO

A lengthy lunar eclipse

A total eclipse of the Moon greets observers of the sky this month. It's perfectly timed for the evening of May 15 across the U.S. and the early morning hours of May 16 in Europe, Africa, and the Middle East. Meanwhile, catch Mercury early in May, ending its period of best evening viewing this year for Northern Hemisphere skygazers. It quickly sinks out of view. This leaves planetary observers to enjoy the pre-dawn treat of four visible planets, starting out with Venus and Jupiter spectacularly close, while Saturn and Mars continue to climb higher in the morning sky.

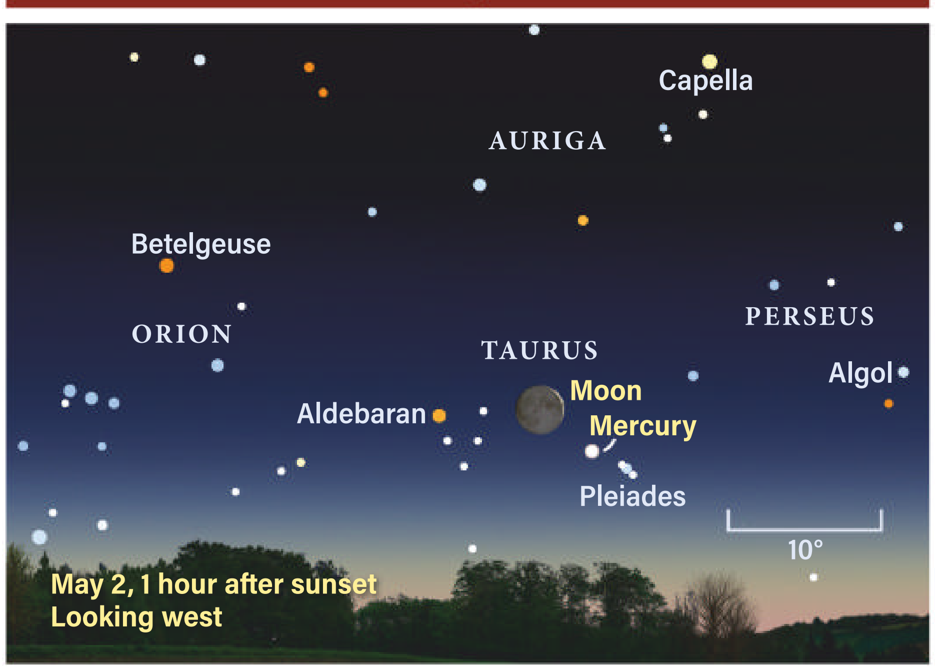
Mercury shines at magnitude 0.5 on May 1, hanging 11° high in the western sky 45 minutes after sunset. The Pleiades (M45) linger nearby and become visible as twilight fades. A 1.2-day-old crescent Moon sits 7° below Mercury and M45 — look for its very slender crescent just above the horizon. Once the sky is dark enough, look also for the binocular Comet C/2021 O3 (PANSTARRS) 3.5° to the right (northwest) of the Pleiades. The comet's path will take it due north into Perseus, and it should be visible over a few nights — but its brightness will certainly surprise observers, either because it is fainter or brighter than predicted, so keep an eye on it.

The crescent Moon slides farther along the ecliptic by May 2, now higher than Mercury (4.5° away). It's a beautiful sight with the Hyades and 1st-magnitude star Aldebaran, the Moon, Mercury, and M45 spanning the western horizon — one not to be missed.

Watch Mercury each evening for as long as you can. The small planet drops to magnitude 1.4 by May 7, becoming harder to spot. It reaches inferior conjunction with the Sun on May 21, and will reappear by next month in the morning sky.

Late on May 15, observers across the U.S. will be greeted with a total eclipse of the Moon, the first of two this year (the second one occurs early on the morning of Nov. 8). The

Hanging in the twilight



On May 2, Mercury, the Moon, and the Pleiades all put in an appearance after sunset. If Comet PanSTARRS doesn't disappoint, you'll find it 8° north of Mercury. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

A **TOTAL LUNAR ECLIPSE** occurs overnight on May 15/16. Totality will last a whopping 85 minutes.

Full Moon is two days from perigee, spanning nearly 33' as it crosses the central part of Earth's shadow, resulting in a longer-than-average 85-minute period of totality. The eclipse occurs with the Moon located in Libra the Balance; the later evening hours reveal the orange glow of Antares in neighboring Scorpius, providing a lovely complement to the orange-hued eclipsed Moon.

The visibility of the eclipse is time zone dependent. East Coast observers will see the whole eclipse in a dark sky. In the Midwest, the Full Moon rises in the eastern sky with the penumbral stages underway, enhancing the effect of the subtly progressing shadow. Observers in the Mountain time zone see the partial eclipse already underway in twilight. From the West Coast, the onset of totality occurs in twilight and the later stages of the eclipse are visible in a dark sky.

The lunar eclipse begins with the penumbral shadow — a subtle shading barely visible on the Moon's lower limb — at 9:32 P.M. EDT. The Moon reaches the dark edge of the deep umbral shadow at 10:27 P.M. EDT. Dusky gray first creeps across the lunar surface and, as more of the Moon sinks into the shadow, an orange coloring will become noticeable, particularly through a telescope.

— Continued on page 38

RISING MOON | Multiplying in the Sea of Fertility

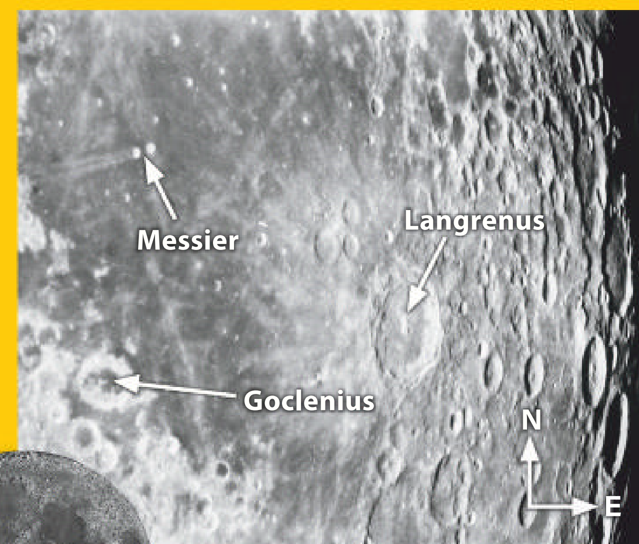
TO THE EYES OF A NEWCOMER, Tycho's terrific ray system near Full phase is one of the most impressive features on the Moon. Put on your shades or screw in a filter to reduce the glare, and let's follow one ray across to the Sea of Fertility (Mare Fecunditatis). Through a scope with a diagonal, this is to the upper left of Tycho, while in a Newtonian this is to the lower left. The ray first passes through the Sea of Nectar and practically pierces the small crater Rosse.

After crossing some highlands, it seems to skip over the perfectly round, lava-filled crater Goclenius, then continues across the rest of the large impact basin that is the Sea of Fertility. Did the higher elevations of the highlands and crater rims produce ray shadows where no ejecta material could fall?

On the opposite shore, numerous short rays spread out from Langrenus like spokes on a bicycle wheel. In the center north, you can't miss the really cool parallel rays shooting out of the double crater Messier. Next, follow the two long rays crossing from north to south. They converge on their source, the large crater Furnerius, itself straddled by two small streak systems. You have from May 9 to 17 to ride the rays.

The incessant solar wind darkens the lighter streaks over time, but in a future so remote that these have disappeared, humanity may have already moved on from our current home.

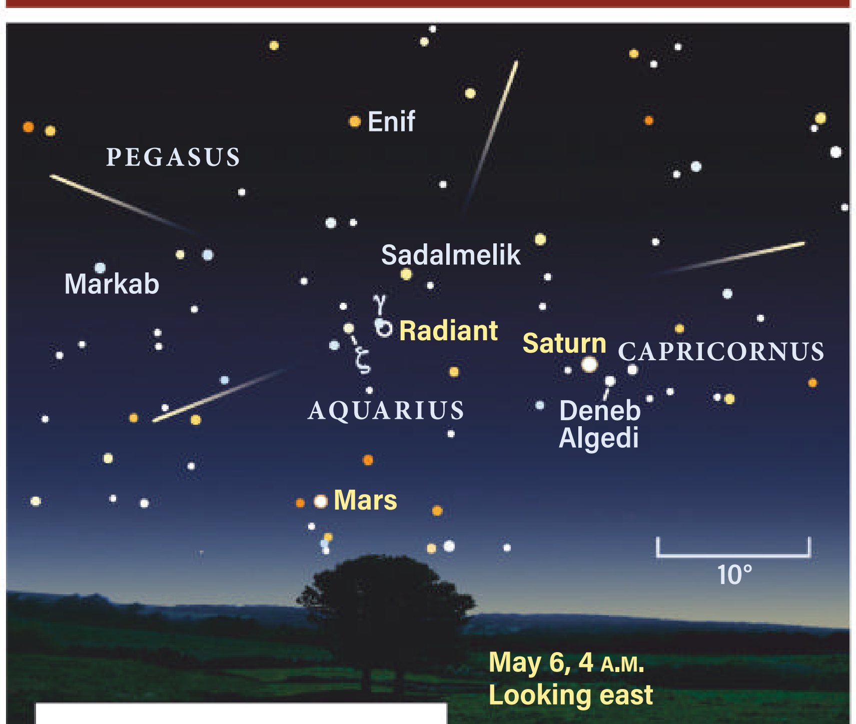
Goclenius



The large crater Langrenus is hard to miss, but more features abound in the Sea of Fertility. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | In favor

Eta Aquariid meteor shower



ETA AQUARIID METEORS
Active dates: April 19–May 28
Peak: May 6
Moon at peak: First Quarter
Maximum rate at peak: 50 meteors/hour

The Eta Aquariids' radiant remains low in the early morning hours for Northern Hemisphere observers.

THE ETA AQUARIIDS are favorable this year due to a near-First Quarter Moon that sets between midnight and 1 A.M. local time, offering dark skies during the early morning hours of the May 6 peak. The shower is active from April 19 through May 28, as Earth sails through debris that Halley's Comet shed during one of its many orbits.

On mornings away from the peak, rates are very low for Northern Hemisphere observers due to the low altitude of the radiant. The radiant lies near Zeta (ζ) and Gamma (γ) Aquarii, and rises shortly before 3 A.M. local time in the continental U.S. It reaches an altitude of nearly 20° one hour later, just as the first signs of twilight begin. The low altitude attenuates the zenithal hourly rate of 50 meteors per hour down to an expected observable rate of five to 10 per hour. These swift meteors travel at some 40 miles per second.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

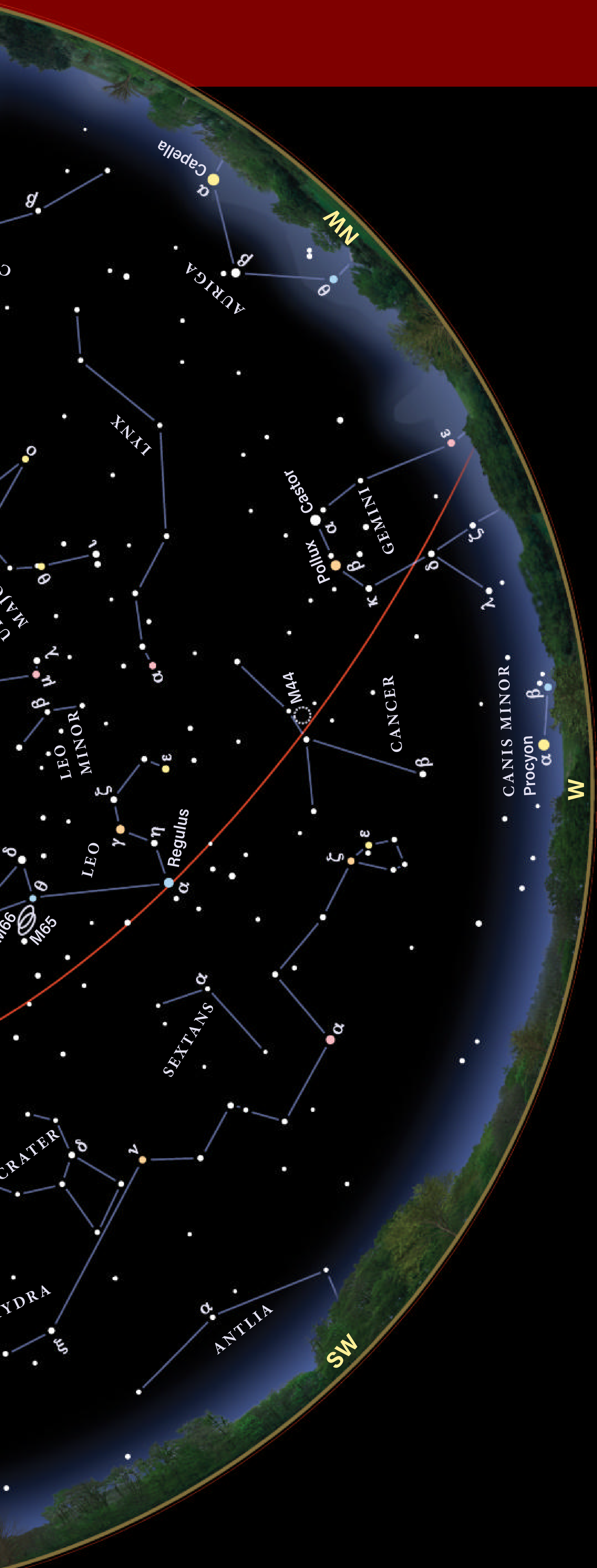
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



MAY 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

2 The Moon passes 1.8° south of Mercury, 10 A.M. EDT

4 The Moon passes 0.008° south of dwarf planet Ceres, 10 A.M. EDT

5 Uranus is in conjunction with the Sun, 3 A.M. EDT

The Moon is at apogee (251,833 miles from Earth), 8:46 A.M. EDT

6 Eta Aquariid meteor shower peaks

8 First Quarter Moon occurs at 8:21 P.M. EDT

10 Mercury is stationary, 7 P.M. EDT

16 Full Moon occurs at 12:14 A.M. EDT; total lunar eclipse

17 The Moon is at perigee (223,879 miles from Earth), 11:27 A.M. EDT

Mars passes 0.6° south of Neptune, 7 P.M. EDT

21 Mercury is in inferior conjunction, 3 P.M. EDT

22 The Moon passes 4° south of Saturn, 1 A.M. EDT

Last Quarter Moon occurs at 2:43 P.M. EDT

24 The Moon passes 4° south of Neptune, 6 A.M. EDT

The Moon passes 3° south of Mars, 3 P.M. EDT

The Moon passes 3° south of Jupiter, 8 P.M. EDT

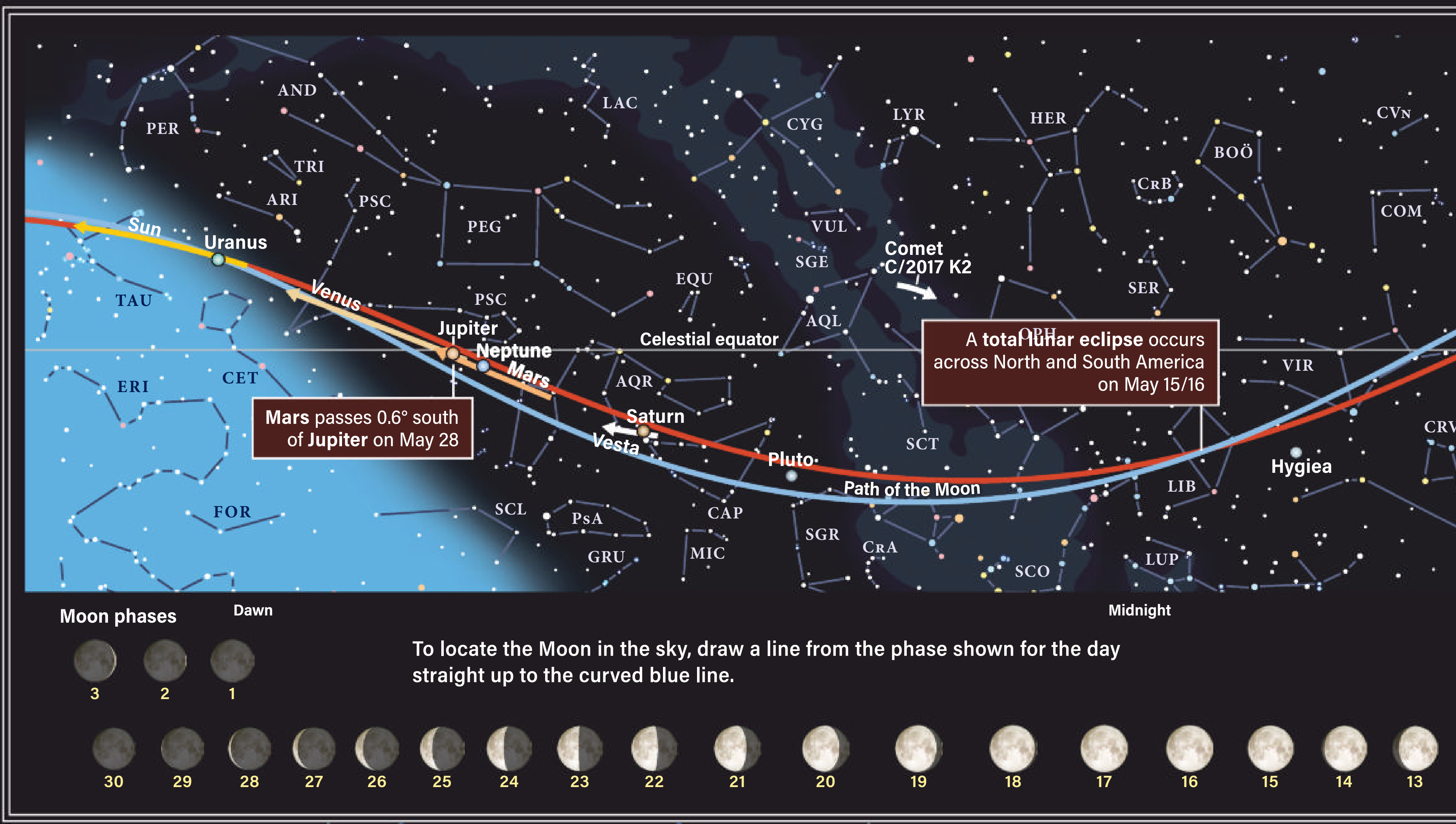
26 The Moon passes 0.2° south of Venus, 11 P.M. EDT

28 The Moon passes 0.3° south of Uranus, 10 A.M. EDT

Mars passes 0.6° south of Jupiter, 8 P.M. EDT

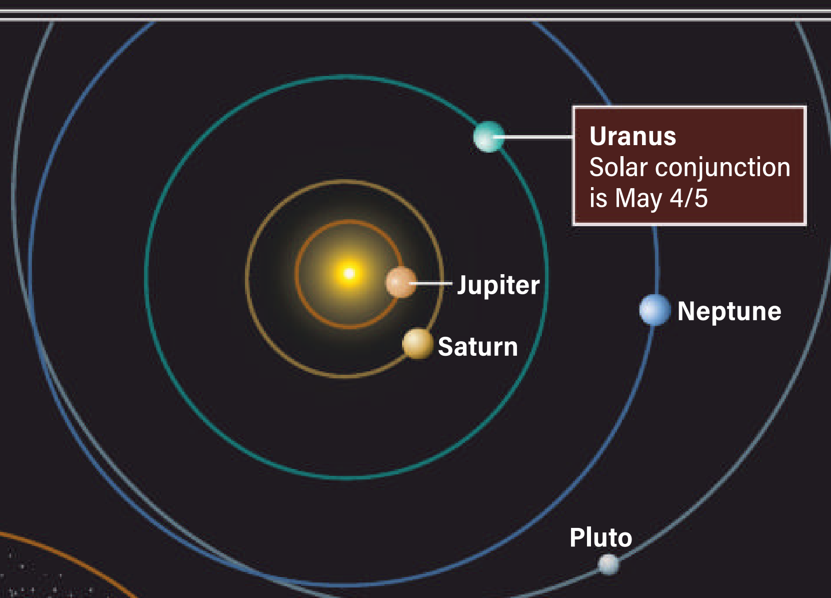
30 New Moon occurs at 7:30 A.M. EDT

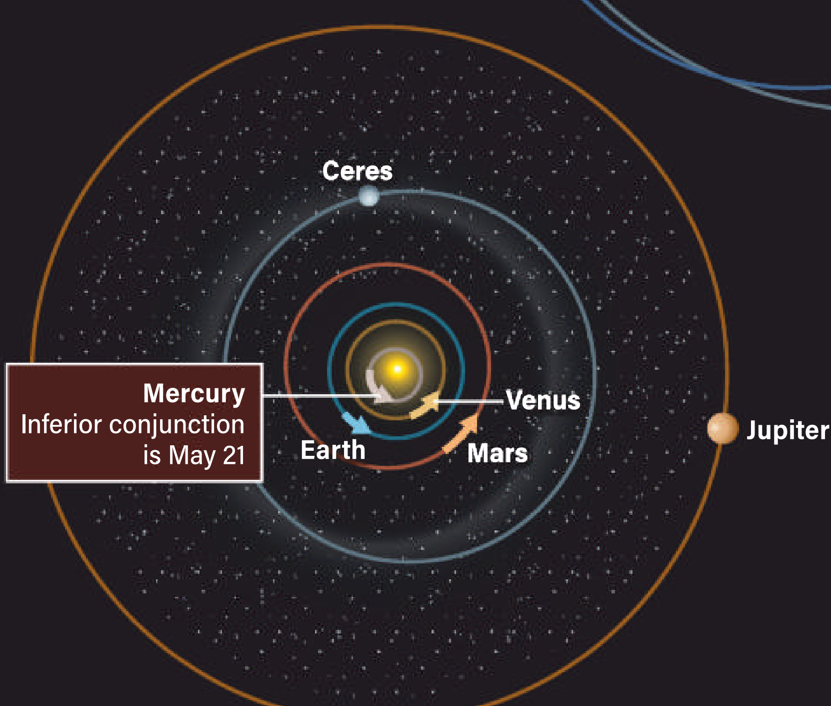
PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

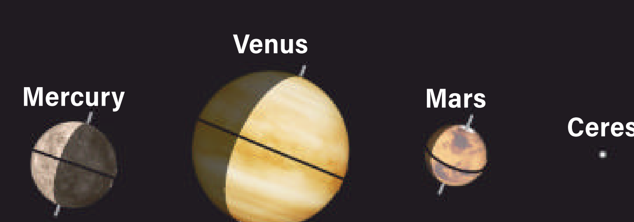
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

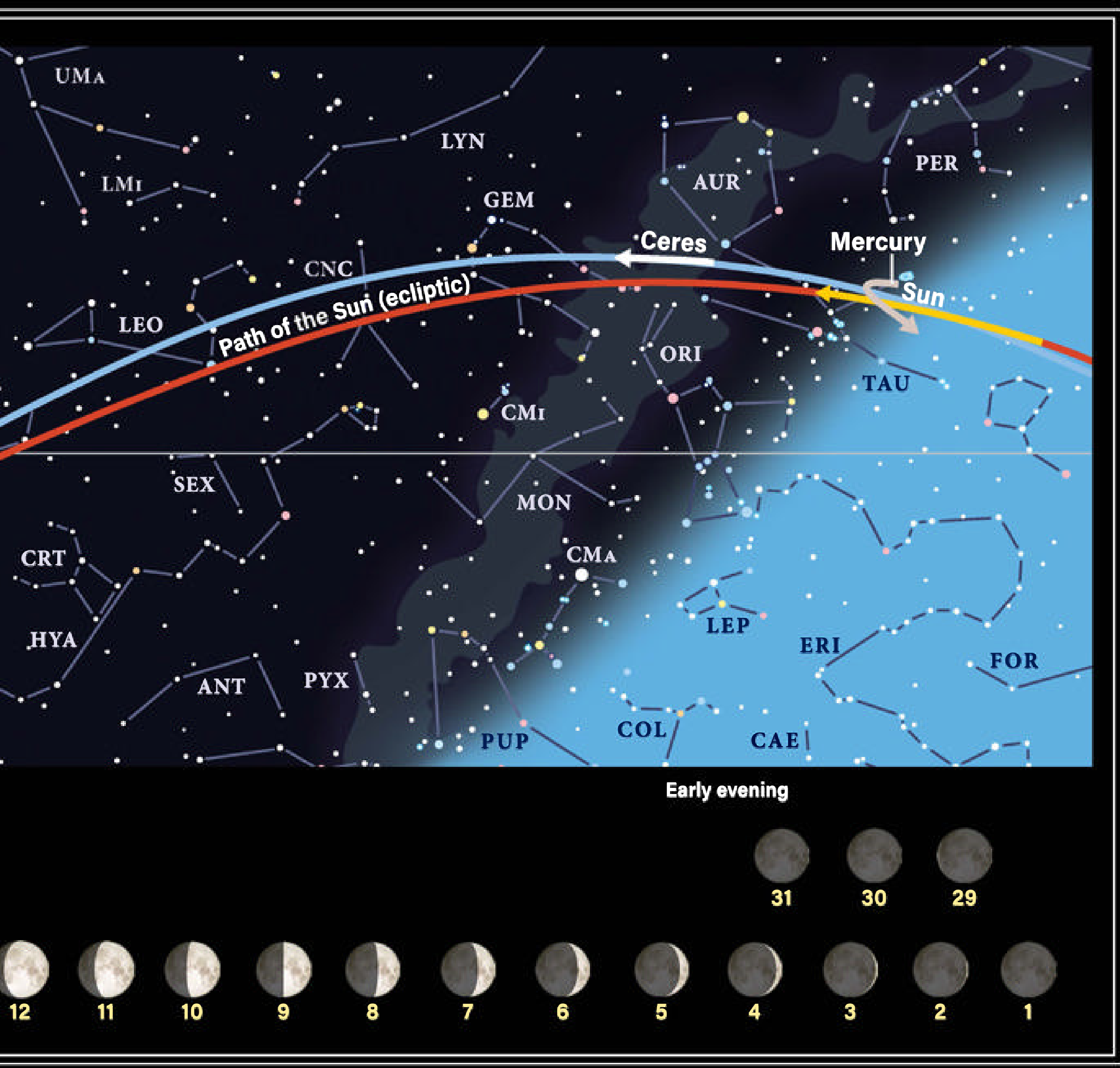
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	May 1	May 15
Magnitude	0.5	–4.0
Angular size	8.3"	15.2"
Illumination	33%	72%
Distance (AU) from Earth	0.815	1.101
Distance (AU) from Sun	0.375	0.728
Right ascension (2000.0)	3h51.5m	0h53.8m
Declination (2000.0)	22°56'	3°47'

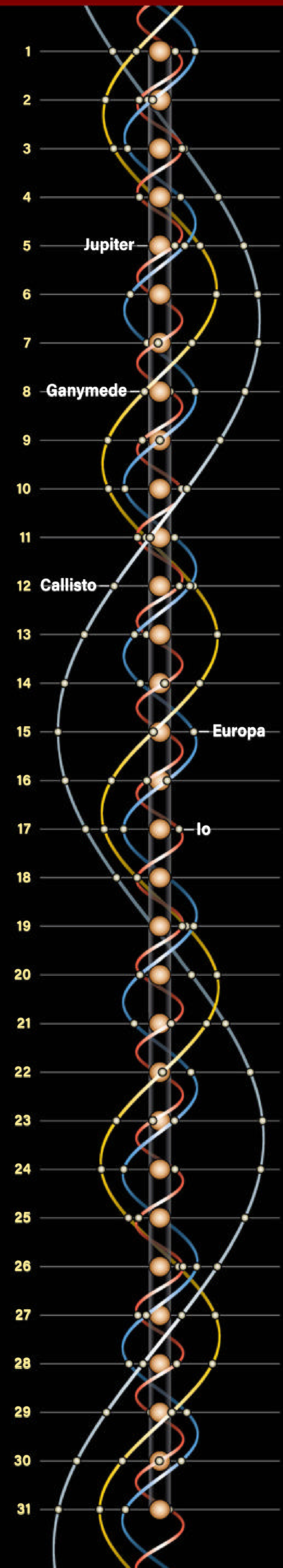
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

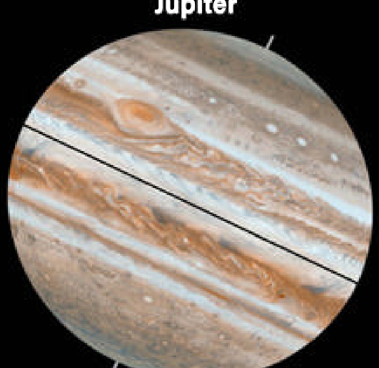
MAY 2022

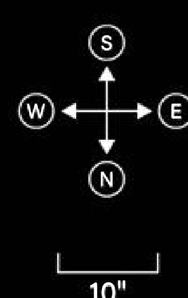


JUPITER'S MOONS

Dots display positions of Galilean satellites at 5 A.M. EDT on the date shown. South is at the top to match the view through a telescope.

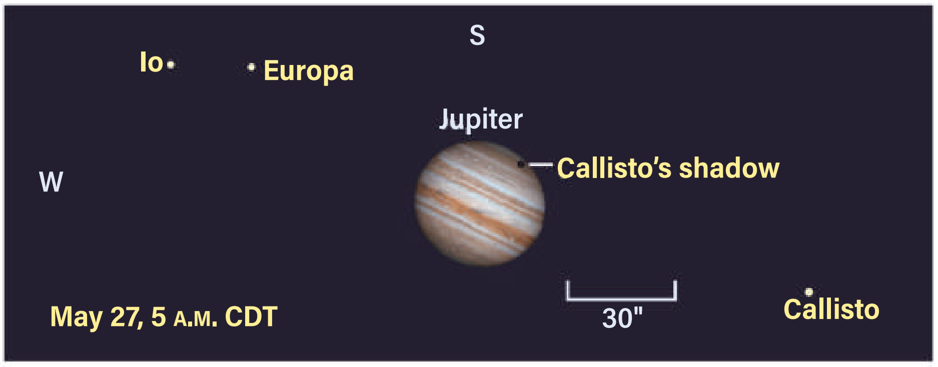






MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
May 15	May 15	May 15	May 15	May 15	May 15	May 15
0.8	8.9	-2.2	0.7	5.9	7.8	15.2
6.0"	0.4"	35.8"	16.9"	3.4"	2.2"	0.1"
88%	99%	99%	100%	100%	100%	100%
1.550	3.371	5.505	9.852	20.702	30.422	34.074
1.391	2.619	4.969	9.891	19.704	29.918	34.523
23h34.1m	5h58.1m	0h03.5m	21h49.0m	2h50.8m	23h42.0m	20h03.1m
-4°36'	26°36'	-0°50'	-14°20'	16°00'	-3°11'	-22°28'

Southern spot



On the morning of May 27, Callisto's large shadow transits the south polar regions of Jupiter. While this occurs, all four Galilean moons are visible. Not shown here, Ganymede lies farther east.

Totality lasts from 11:29 P.M. to 12:53 A.M., spanning 85 minutes (all times are EDT unless otherwise noted). Mid-totality occurs at 12:11 A.M. For observers along the eastern coast of the U.S., the Moon then stands at least 25° high in the southern sky. Our satellite appears at progressively lower altitudes for observers farther west. Enjoy the spectacular view of the deep orange Full Moon floating in a star-studded dome. Enhanced views from the country will reveal the summer Milky Way rising in the southeastern sky, normally blocked out by the light of the uneclipsed Full Moon. The partial phases progress until 1:55 A.M. and the final penumbral trace leaves the disk imperceptibly by 2:50 A.M.

The ringed planet **Saturn** rises around 3 A.M. local time on May 1, located in eastern Capricornus the Sea Goat. By the end of May, it's up around 1 A.M. It starts the month at magnitude 0.6 and stands 1.7° north of Deneb Algedi, which shines two magnitudes fainter. The planet is best viewed in the hour before dawn, when it stands more than 20° high in the southeast.

Through a telescope, Saturn displays a 17"-wide disk and its fine rings span more than twice that distance. The rings' tilt is noticeably different than last year, and in May and June they're at 12° to our line of sight. This is the minimum angle for 2022 — the tilt increases to 15° through opposition later in the year.

On May 6, the main-belt asteroid 4 Vesta stands between Saturn and Deneb Algedi. The 7th-magnitude asteroid is within easy reach of binoculars, only 0.7° south of Saturn. Vesta treks eastward and remains within about 1° of Saturn for three days either side of the 6th.

Mars rises shortly before 4 A.M. local time on May 1, and nearly hour earlier in late May. It brightens from magnitude 0.9 to 0.7 during the month as it treks from eastern Aquarius into Pisces. On May 8, it stands within 0.5° of 4th-magnitude Phi (ϕ) Aquarii. Of greater interest is May 17 and 18, when Mars glides south of **Neptune**. The actual moment of conjunction takes place during daylight hours on May 17 for U.S. observers, but on the morning of the 18th, you'll find the 8th-magnitude, bluish glow of Neptune 33" northwest of the Red Planet.

In the run-up to Mars' second conjunction of the month, look out on the early morning

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)

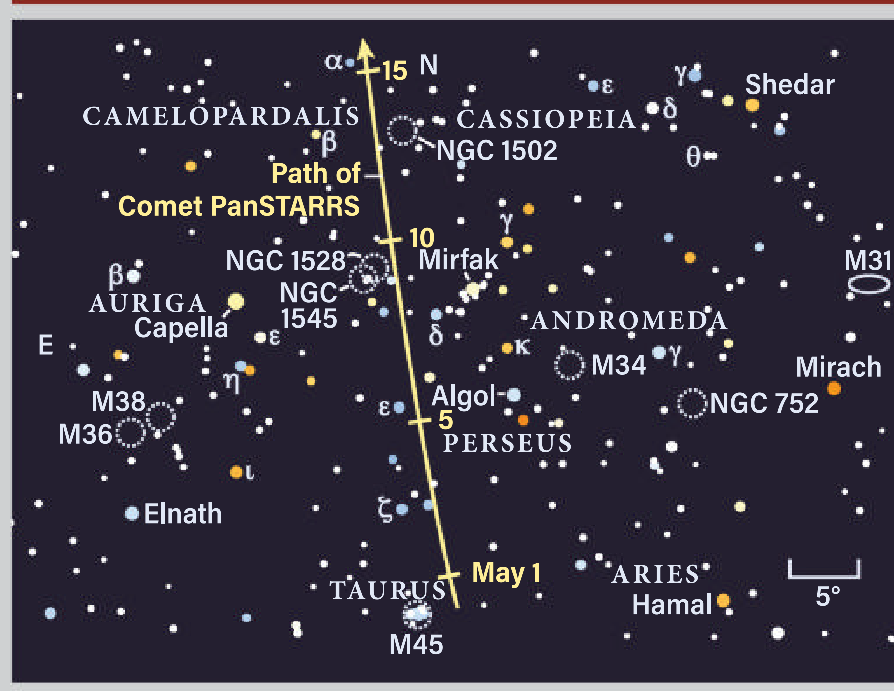
MORNING SKY
Venus (east)
Mars (east)
Jupiter (east)
Saturn (southeast)
Uranus (east)
Neptune (east)

COMET SEARCH | Second comet of the decade?

READY TO WITNESS a fantastic glowing sword standing straight up from the recently set Sun? Comet C/2021 O3 (PanSTARRS) could be it. Or it could instead dissolve suddenly in a whimper.

The night of May 2 could go down in history: In deepening twilight, Comet PanSTARRS sits photogenically a few degrees right of Mercury (magnitude 0.6), while the Pleiades star cluster (M45) sparkles between them and a thin crescent Moon full of earthshine smiles just off to the left. Plan for travel if you can. We will have three days' notice that the performance is on. This is a rare opportunity.

Comet C/2021 O3 (PanSTARRS)



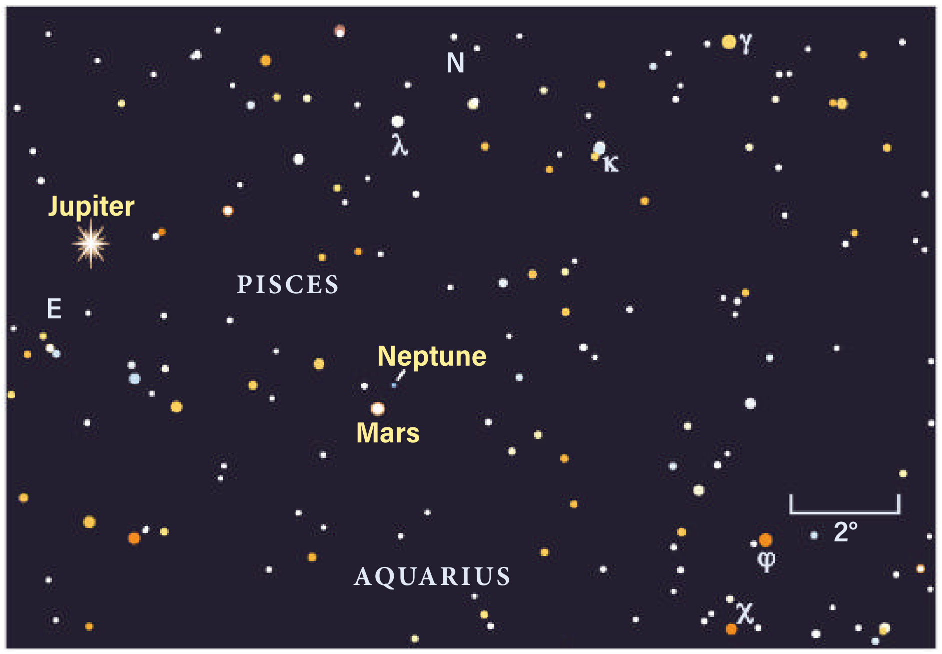
Catch Comet PanSTARRS May 2 near M45, the Moon, and Mercury. (The last two are not shown here — see page 32 for their relative positions that day.) Find updated finder charts for the latter half of May on Astronomy.com.

Though PanSTARRS is fading after perihelion on April 21, beneficial geometry kicks in during early May. Dust lights up when we see it in the direction of the Sun. The forward scattering angle is at a minimum on the 4th, similar to what we saw with comets C/2006 P1 (McNaught) and C/1975 V1 (West). In the nights following, the main body shifts up and away into Perseus but the dust swings into alignment.

Ignore the waxing Moon to watch PanSTARRS as long as possible. It slowly fades into binocular range while climbing toward Polaris. On May 10, it passes the picturesque starfield of Perseus' left arm, which contains the star cluster NGC 1528 and its compact neighbor NGC 1545. Give it a try anyway on the moonglow weekend of May 13 to 15, some 3° from Kemble's Cascade and NGC 1502.

Although PanSTARRS probably won't trigger the clickbait hype of media newsfeeds, don't slip into "Oh, I'll see it tomorrow" mode and miss out.

Red vs. blue



By May 18, Mars and Neptune are 33" apart following a daylight conjunction on the 17th. Seeing Neptune will require binoculars. Jupiter is also nearby.

of May 25 to see the waning crescent Moon in the vicinity of Mars and Jupiter, which stand 2.4° apart. The Moon floats 5.5° east of Jupiter. A few days later, on May 28, Mars slides 0.6° south of Jupiter. Rising together shortly before 3 A.M. on the 29th, the two planets are still the same distance apart by 5 A.M. local time, standing 25° high in the eastern sky. Over in the eastern end of Pisces is Venus, which rises around 4 A.M. local time.

Jupiter shines at magnitude –2.2 and Mars is magnitude 0.7. Their color contrast is stunning. The two planets remain within 1.5° of each other through May 31. Through a telescope, Mars is still tiny, spanning 6" compared with Jupiter's 37".

May opens with **Jupiter** and **Venus** still close together following their late April conjunction. The stunning pair of planets rises just after 4 A.M. local time, just 33' apart. Venus shines at magnitude –4.1 and Jupiter is dimmer but still brilliant at magnitude –2.1. A low-power telescope will show both planets beautifully. Venus boasts a 17"-wide disk that is 68 percent lit, and Jupiter spans 35" and is flanked by its four Galilean moons, two on each side. Follow them into early twilight — when Venus is less dazzling — for some of the best views.

Over the following days, Venus and Jupiter separate, with Jupiter extending its angular distance from the Sun while Venus reduces its elongation. Jupiter is a fine object with improving visibility as the month progresses. A notable transit of Callisto's shadow occurs in the early morning of May 27. You can spot the shadow moving across Jupiter's southern polar region over a period of nearly 2.5 hours, beginning at 5:31 A.M. EDT. Jupiter's largest moon, Ganymede, casts its own shadow across Jupiter's cloud tops on May 29, beginning at 3:49 A.M. EDT. The transit is underway as Jupiter rises in the Midwest and in its later stages for West Coast observers.

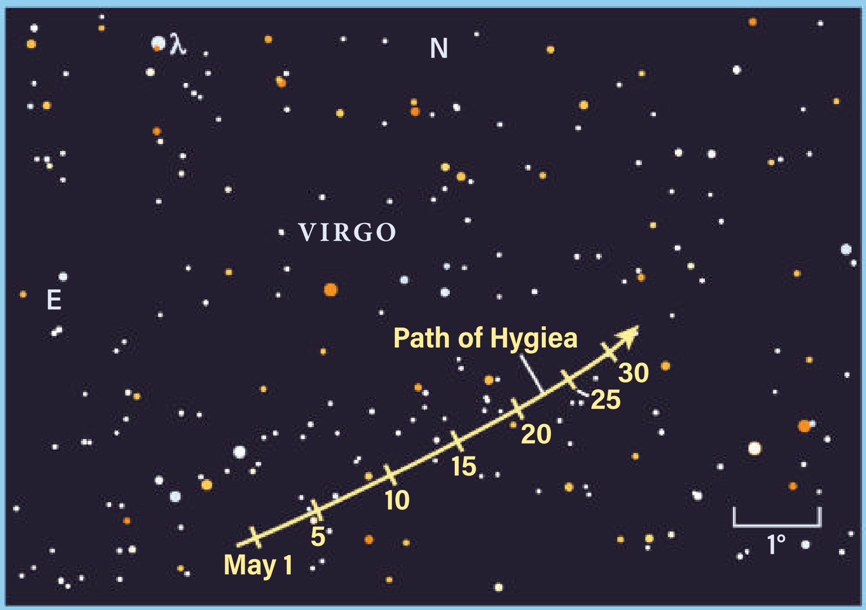
LOCATING ASTEROIDS
Look south of Lambda

AS TWILIGHT FADES on mild spring evenings, the blue luminary Spica climbs in the southeastern sky. Following it 40 minutes later and a bit to the south is the main-belt asteroid 10 Hygiea. Far from the confusing swarms of Milky Way stars, it won't be hard to track. Glowing at magnitude 9.3, Hygiea will need a 4-inch scope from the suburbs to catch your eye. Star-hoppers should start with Lambda (λ) Virginis and make their way south.

In a low-power field of view up to 1° across, only one or two stars challenge Hygiea for brightest object. That's pretty much how Frenchman Annibale de Gasparis discovered it in April 1849, but on the other side of Spica. Patiently comparing eyepiece views to star charts and picking out the stranger was still the only way to uncover the unknown at that time, nearly 50 years after 1 Ceres first came to light between the orbits of Mars and Jupiter.

It will be a long time before a spacecraft visits Hygiea. Modern studies show it is quite round at about 280 miles across, and its key feature is its low reflectivity of only 7 percent — barely brighter than the Moon's dark surface and a dark cousin to shiny 4 Vesta's 40 percent. Because it shares characteristics with stony meteorites, some astronomers have deduced that Hygiea completely shattered in a huge impact long ago and later coalesced into a low-density glob.

Sparse starlight



Hygiea is crossing a region with few bright stars to provide competition, making it easy to spot the main-belt world.

By May 27, Venus spans 14" and is 76 percent lit. A waning crescent Moon stands less than 4° away in morning twilight. Earlier in the day, notably for those in southeast China and southeast Asia, the Moon occults Venus, passing in front of it from our point of view.

The morning star's visibility continues through the end of May, when the planet rises just before 4 A.M. local time and stands about 10° high as twilight begins.

Uranus is in conjunction with the Sun on May 5 and consequently is not visible most of the month. The ice giant begins to reappear, awash in the morning twilight, by the end of May.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

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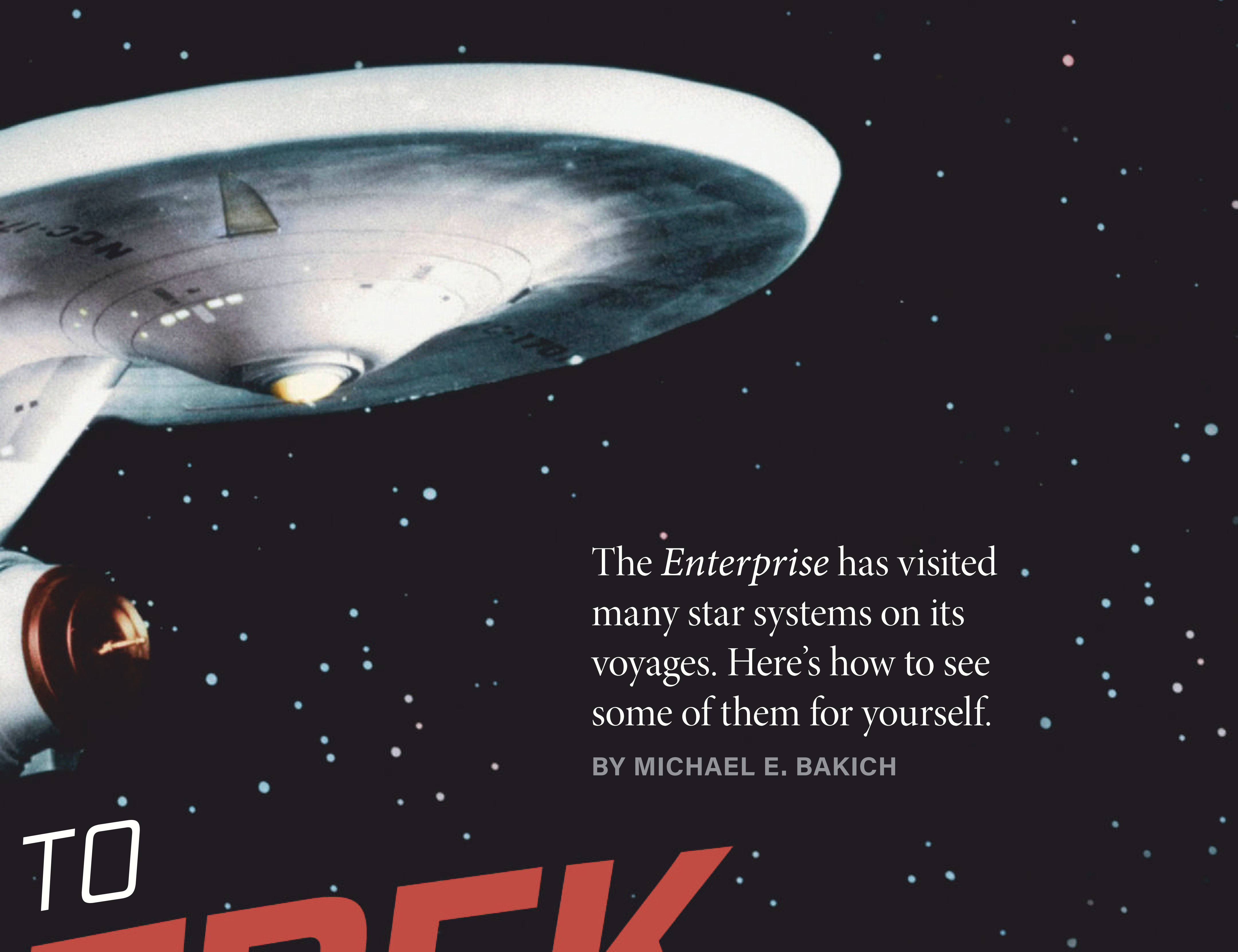
AN OBSERVER'S GUIDE STAR

OLGA POPOVA/DREAMSTIME

MANY READERS OF *Astronomy* can point back to televised science fiction as their first introduction to the universe. For some — like me — it was *The Outer Limits*, which had a brief run starting in 1963. Others may have been influenced by *The Twilight Zone* (1959), *Lost in Space* (1965), or *The Invaders* (1967).

By far, however, the TV show that gave the most astronomy buffs their start exploring space was *Star Trek*, which began a three-season run at 8:30 P.M. EDT on Thursday, Sept. 8, 1966. This groundbreaking television



TO TREK

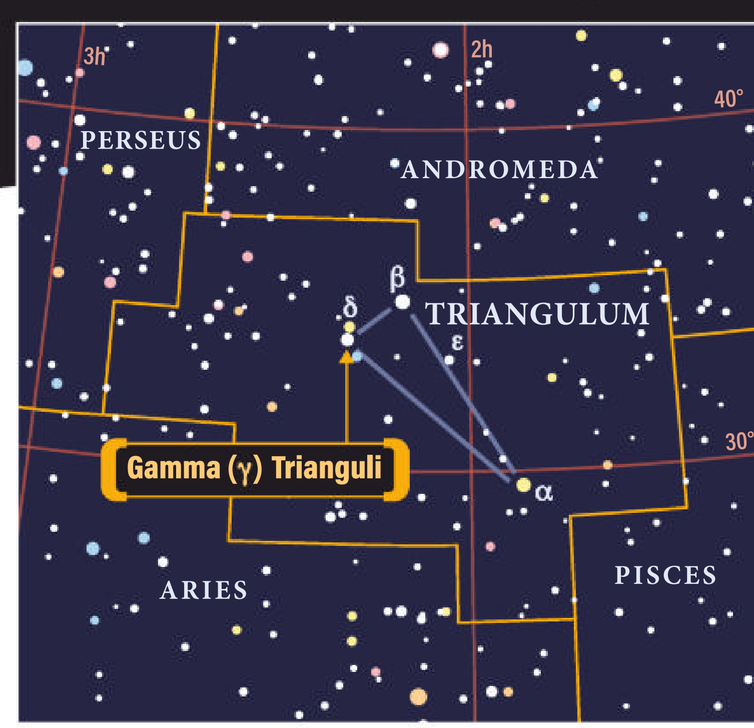
The *Enterprise* has visited many star systems on its voyages. Here's how to see some of them for yourself.

BY MICHAEL E. BAKICH

show was followed by *Star Trek: The Next Generation* (1987), *Star Trek: Deep Space Nine* (1993), *Star Trek: Voyager* (1995), *Star Trek: Enterprise* (2001), *Star Trek: Discovery* (2017), and *Star Trek: Picard* (2020), along with various movies, animated series, and lots of books and comics.

During the five and a half decades that followed the first show, now often referred to as *The Original Series*, the *Enterprise* has visited hundreds of planets. Of course, each one originated in some writer's imagination. But I wondered how many of those destinations were placed in a star system visible in our sky. A lot, it turns out. I stopped counting at 50.

What follows is a list that combines some of the brightest stars in our sky with several not-so-bright ones, all of them important in the *Star Trek* universe. The next time you look at one of these stars, let your mind drift back to 1966, when people — through their television sets — voyaged to distant worlds. Indeed,



TOP: Starting with the NCC-1701, the *Enterprise* carried crews to far-flung worlds throughout the galaxy. Many of these star systems are observable right from your backyard. MARY EVANS/AF ARCHIVE/CINETEXT BILDARCHIV/EVERETT COLLECTION

ABOVE: The *Enterprise* once visited the faintest of the three stars outlining the constellation Triangulum, Gamma Trianguli, discovering a world ruled by the supercomputer Vaal. *ASTRONOMY:* ROEN KELLY

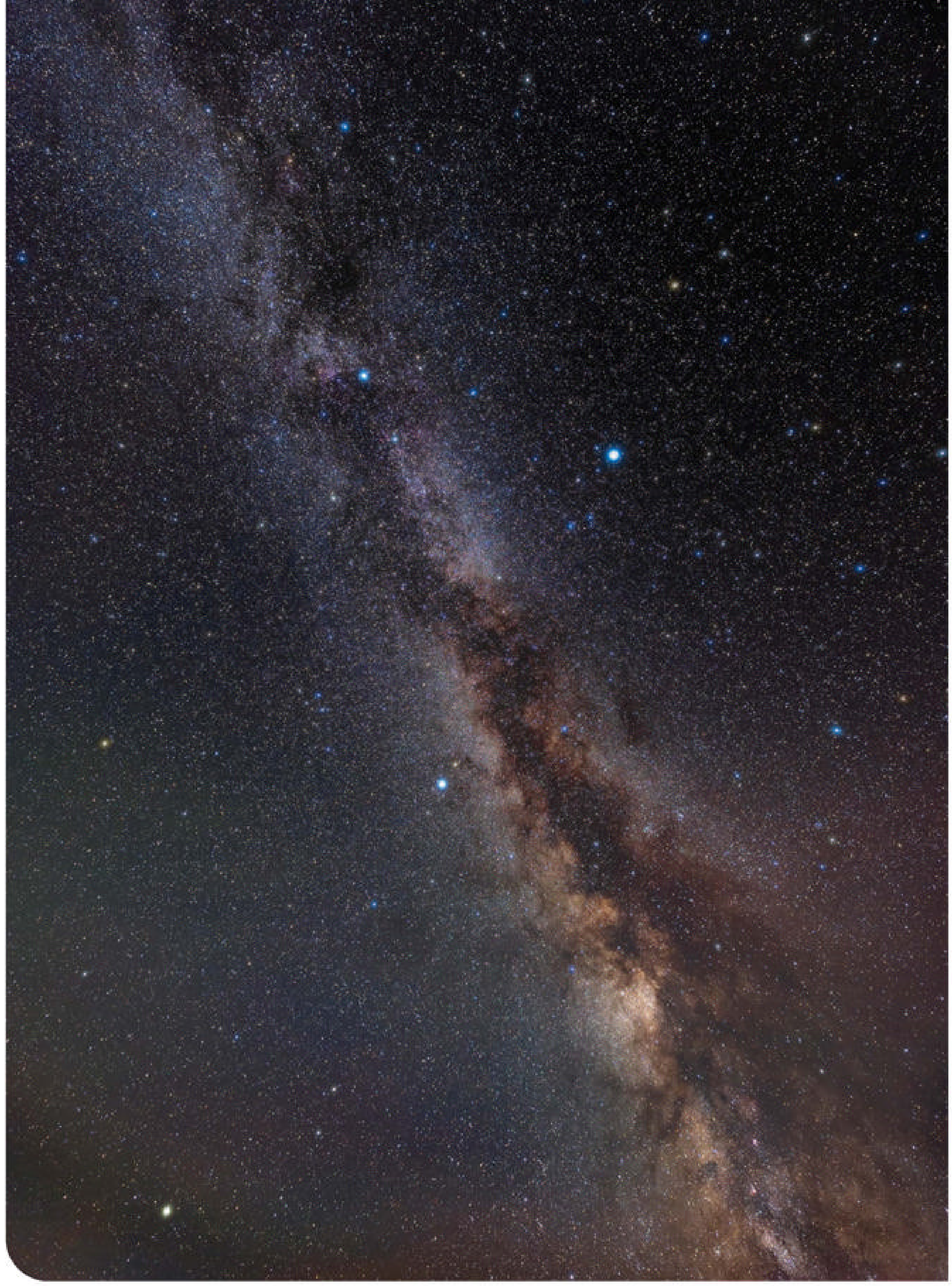
with all the recent exoplanet discoveries, it's not hard to imagine that an alien civilization might exist where no one has gone before, on a planet revolving around one of the stars of *Star Trek*.

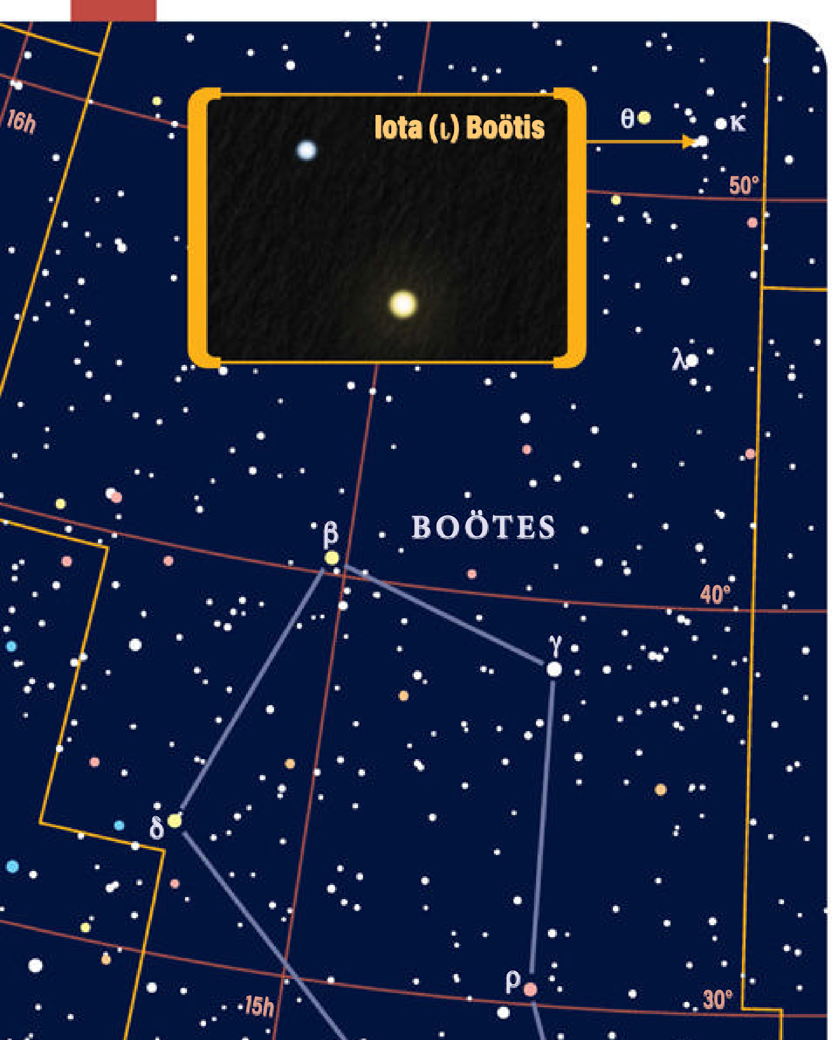
Strange new worlds

Besides Earth, probably the most important planet in *Star Trek* is Vulcan, homeworld of Mr. Spock. Early on, some official reference books listed magnitude 3.7 Epsilon (ε) Eridani as the star around which it orbited. During an episode of *Enterprise*, however, Chief Engineer Tucker states that Vulcan is 16 light-years from Earth. And Epsilon Eri is only 10.5 light-years away.

Current *Trek* star maps place Vulcan in the **Omicron² (o²) Eridani** system. This triple star, also known as Keid and 40 Eri, is some 16.3 light-years from Earth. Its primary glows at magnitude 4.4. To find it, look 15° west of Rigel.

The brightest star visited by any *Star Trek* crew on television or film is **Canopus** (Alpha [α] Carinae), which observers can spot from the southernmost states. Shining at magnitude –0.7, it's the second-brightest star in our night sky. It featured in *The Original Series* episode "The Ultimate Computer." In





ABOVE: The Summer Triangle is a familiar warm-weather asterism comprising the bright stars Vega, Deneb, and Altair. Fictional worlds circling each of these three stars are featured throughout *Star Trek*. ALAN DYER

FAR LEFT: The star Iota Boötis is known in *Star Trek* as Denobula Triaxa. As its name might indicate, this was once believed to be a trinary system; astronomers now suspect the third star is not associated with the binary. *ASTRONOMY*: ROEN KELLY. INSET: JEREMY PEREZ

LEFT: The *Enterprise*'s transporter allows crew to quickly move from the ship to the worlds of any star system they're visiting. EMILY743/DREAMSTIME

the episode, which takes place in 2268, the scientist Richard Daystrom installs a tactical computer aboard the *Enterprise*. The device can control the ship with some 5 percent of its normal crew. Its first task is to survey the inhabited planet Alpha Carinae II.

Note that the brightest nighttime star, Sirius (Alpha Canis Majoris), also has a planetary system whose members served as settings for stories, but only in *Star Trek* books or video games.

The third-brightest star in our sky, **Alpha Centauri**, is a triple system that's famous as the nearest star system

to our own. It's also famous in the *Star Trek* universe, hosting no less than 22 planets. Thirteen of them circle Rigil Kentaurus (Alpha Cen A), five orbit Alpha Cen B, and four more travel around Proxima Centauri (Alpha Cen C).

What's more, three of these planets are populated. Including outposts and space stations, this system supports some 21 billion inhabitants. When you spot Alpha Centauri (only visible from latitudes south of 30° north), imagine how cool it would be if, in reality, any planets around those stars contained the simplest form of life, let alone intelligent life.

Our next entry is one that requires some searching to see. In the *Star Trek* universe, more than 150 planetary civilizations belong to a democratic society known as the United Federation of Planets. Such a body often needs neutral ground for negotiations: a planet named Babel, which orbits the star **Wolf 424**.

This star, also known as FL Virginis, is a system of two red dwarfs a bit more than 14 light-years away that together glow just brighter than a meager 13th magnitude. You'll need an 8-inch or larger scope, a dark site, an excellent star chart (or software), and lots of patience to track it down. But for a true fan of *Star Trek*, that's a small price to pay to spot a star whose planet has two episodes — "Journey to Babel" and "Babel One" — named for it.

The stellar moniker Menkar may not be familiar to *Star Trek* fans. But call this star **Ceti Alpha**, and it will immediately conjure up the image of Khan Noonien Singh. This character first appeared in *The Original Series* episode "Space Seed," and then in the movies *Star Trek II: The Wrath of Khan* and *Star Trek Into Darkness*.

Though referred to in *Star Trek* as Ceti Alpha, a luminary that has at least six planets in orbit, it's more correct to call this star Alpha Ceti. However, *Star Trek*'s writers aren't the only ones to break convention regarding the star's designation. The alpha star is usually the brightest star in a constellation. Not in Cetus the Whale, though. That honor goes to Diphda (Beta [β] Ceti), which, at magnitude 2.0, is 58 percent brighter than magnitude 2.5 Alpha. Both stars are easy to spot in the Northern Hemisphere's autumn sky.

ABOVE and LEFT: Small, furry, and fast-multiplying, Tribbles hail from Iota Geminorum. TRIBBLES: PARAMOUNT/COURTESY EVERETT COLLECTION. CHART: *ASTRONOMY*: ROEN KELLY

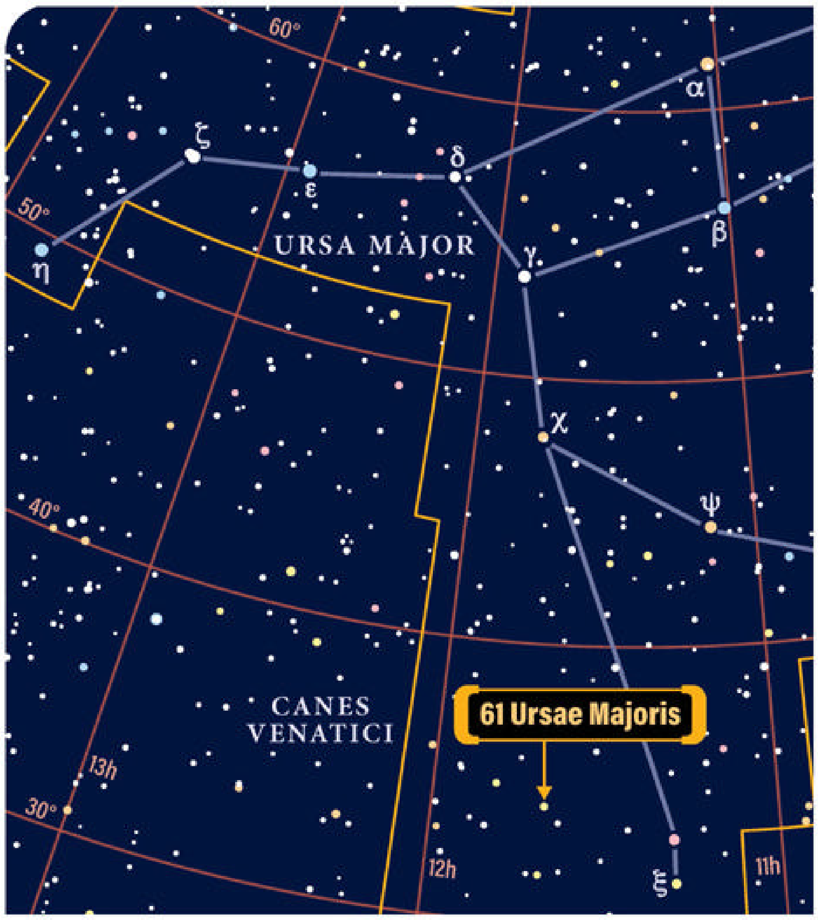
BELOW: A stamp shows the *Enterprise* en route to new worlds and new stars. OLGA POPOVA/DREAMSTIME

Three to beam up

A triad of stars well known to amateur astronomers is the Summer Triangle: **Vega** (Alpha Lyrae), **Altair** (Alpha Aquilae), and **Deneb** (Alpha Cygni). In *Star Trek*, Vega hosts at least nine planets, the main one being Vega IV with a mostly human colony of nearly 5.8 billion inhabitants. This system is referenced in *The Original Series* episode "Mirror, Mirror." Captain James T. Kirk learns that one of the first actions his mirror counterpart took after assuming command of the *Enterprise* (via assassination) was to execute 5,000 colonists on Vega IX.

Now, on to Altair. The most famous planet in the Altair system is Altair VI. In *The Original Series* episode "Amok Time," the *Enterprise* is headed to this planet to attend the inauguration of its new president when it has to divert to Vulcan for Spock's mating ritual.

In *Star Trek*, the name Deneb is used to refer to the "true" Deneb (Alpha Cygni) and also as shorthand for Deneb Kaitos, which is another name for the star Diphda in Cetus. The latter has no



ABOVE: On a galaxy-class starship, navigation to new star systems takes place at the conn. JOSE TERRERO/DREAMSTIME

LEFT: Magnitude 5.3 61 Uma is famous in *Trek* lore for hosting the planet Archer IV — the first Earth-like, or M-class, planet discovered by humans. You can find it with the naked eye from a dark site. *ASTRONOMY*: ROEN KELLY

less than six planets, while the former hosts nine planets, the most important of which are Deneb II and Deneb IV. This second world is the site of Farpoint Station, where the crew in the very first *The Next Generation* episode, "Encounter at Farpoint," meets the ultra-powerful being known as Q.

Tribbles, the Borg, and Denobulans, oh my!

Midway on the sky between the Andromeda Galaxy (M31) and the Pleiades (M45), you'll find the tiny constellation Triangulum. Of its three brightest luminaries, the least apparent is 4th-magnitude **Gamma (γ) Trianguli**. In *The Original Series*, the *Enterprise* visited the planet Gamma Trianguli IV during the episode "The Apple," finding a civilization controlled by a supercomputer named Vaal.

Every *Star Trek* fan — and probably most non-fans — have heard of Tribbles, which debuted in "The Trouble With Tribbles" in the second season of *The Original Series*. Brought aboard the *Enterprise* by merchant Cyrano Jones, they nearly overwhelmed the ship's operations. The homeworld of the furry creatures is Iota Geminorum IV, whose central star, **Iota (ι) Geminorum**, glows at magnitude 3.8 about 4.5° from both Castor and Pollux.

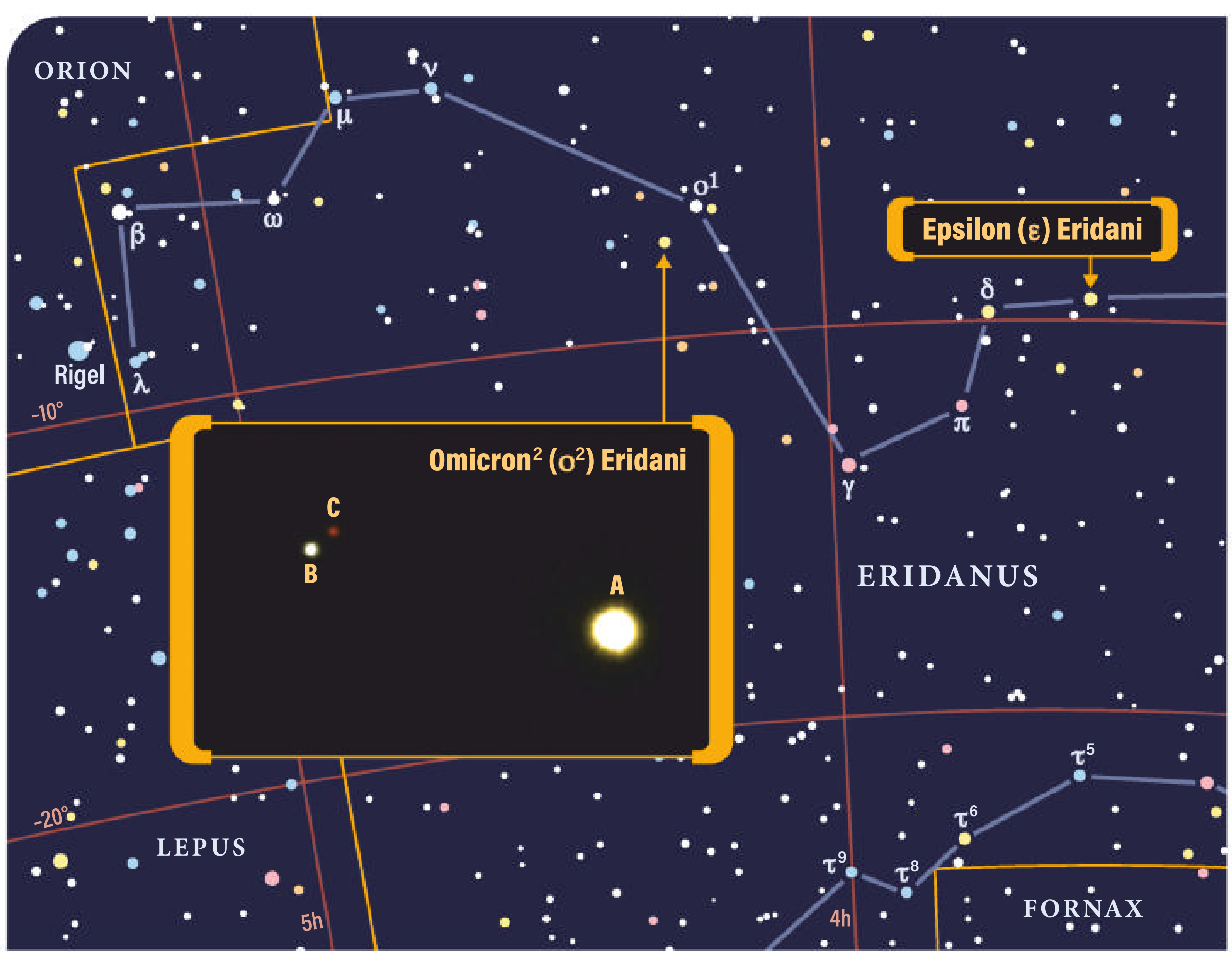
On the other end of the brightness spectrum from most of the stars I've mentioned, **Wolf 359** is incredibly faint. Although it lies less than 8 light-years away, this red dwarf glows meekly at magnitude 13.5. Wolf 359 lies in southern Leo, almost directly on the ecliptic. In *The Next Generation* two-part episode "The Best of Both Worlds," a disastrous battle takes place in this star system between the Federation and the Borg. The real kicker is that the Borg ship is under the

TOP: Khan Noonien Singh is one of the most infamous adversaries in *Star Trek*. After attempting to take control of the *Enterprise*, he was exiled to — and eventually escaped from — a planet circling Menkar, known in *Star Trek* as Ceti Alpha. PARAMOUNT/COURTESY EVERETT COLLECTION

LEFT: Cetus the Whale, located in the lower portion of this shot, contains two famous *Star Trek* stars. Diphda (Deneb Kaitos) is the bright luminary at right and Menkar (Ceti Alpha in *Star Trek*) is in the lower left of the frame. ALAN DYER

2064	2064962	7	9776	626	1276	7612
34	279		89	6589	6547	6587
4768	8967248	7	9798	8969	476	9047
685	3478	8	867	346	34	48
757	898990	8	200	285	923	9
484	947589	7	569	68	678	893

TOP RIGHT: Sirius (at top) reigns as the brightest star in the sky. Coming in second is Canopus, visible just above the horizon in this photo shot in Arizona. Both host planetary systems in *Star Trek*. ALAN DYER



BOTTOM RIGHT: Older *Star Trek* texts claimed the planet Vulcan orbited Epsilon Eridani. But current maps place the famous world around 4th-magnitude 40 Eri A, the brightest member in the Keid (Omicron² Eridani) system. *ASTRONOMY*: ROEN KELLY. INSET: GIUSEPPE DONATIELLO

guidance of Locutus — formerly the *Enterprise*'s Captain Jean-Luc Picard, who was captured and assimilated into the Borg collective, losing his individuality and prior allegiance in the process.

Only an observer familiar with the series *Enterprise* will know the planet Archer IV, named for the captain of the NX-01. It's an important one, however: the first M-class (meaning Earth-like and habitable) planet discovered by humans. To see the luminary around which this fictional world revolves, look toward the southernmost part of the constellation Ursa Major. There, you'll find the Sun-like star **61 Ursae Majoris**, glowing at magnitude 5.3 — just bright enough to spot without binoculars from a dark site.

Enterprise also gave us the wonderfully named Denobula Triaxa, the star we know as **Iota Boötis**. In fantasy, this is a triple star, but reality shows it is binary. Its components glow at magnitudes 4.8 and 8.3. You can spot them easily through any size telescope because their separation is a worthy 39". They also show a nice color contrast, with a yellow primary and the secondary a blue-white. In *Enterprise*, this system is notable as the homeworld of Chief Medical Officer Dr. Phlox.

Resistance is futile

As you can see, a lot of stars in our sky — some familiar, some not — have found their way into the lore of *Star Trek*. The next time you encounter one, let your mind wander a bit and consider that the prospect of life in the universe is a lot more possible now than it seemed in 1966. Live long and prosper!

Michael E. Bakich *is a contributing editor of* Astronomy *who enjoys early* Star Trek *reruns from his home in Tucson, Arizona.*

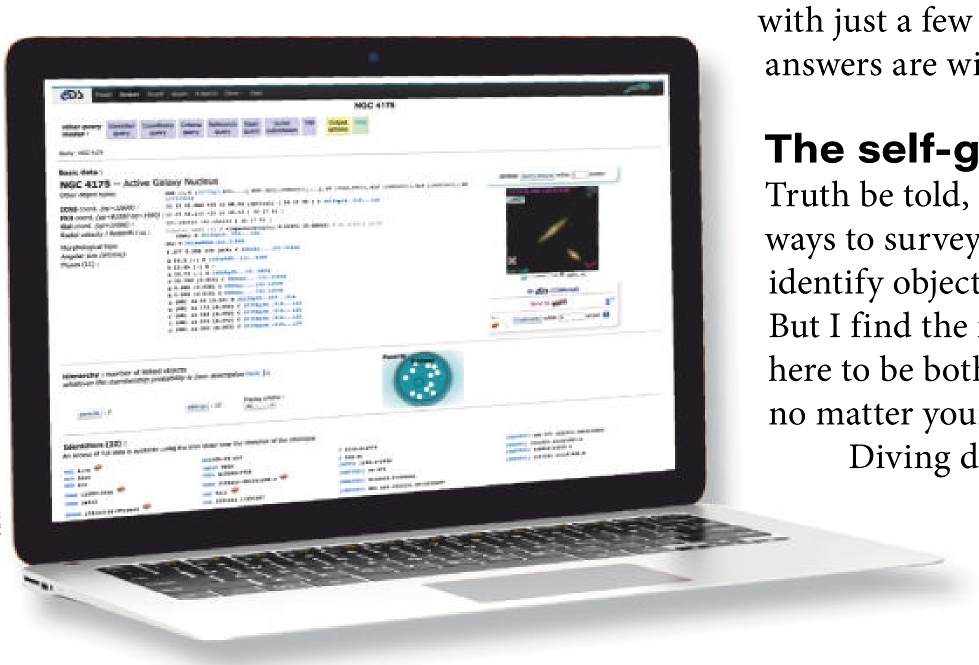
HOW TO identify objects in your ASTROPHOTOS

These free websites are all you need to unlock the mysteries hidden within any deep-sky image.

BY JASON GUENZEL

AN ASTROPHOTOGRAPHER is like a tour guide of the cosmos. In the blink of an eye, we can take viewers thousands of light-years away, drawing their attention to the best celestial sights the universe has to offer.

As an astrophotographer who particularly enjoys imaging distant galaxies, I'm often left scanning deep-sky shots, wondering about all the objects clearly captured in my image and what "faint fuzzies" may be lurking in the background. Long exposures allow even a backyard astronomer to capture some of the most distant objects in the universe. And, unlike guiding visitors through a city, its impossible to memorize every single worthwhile object that your images may catch. Unless you already know how to separate fainter objects from the background for further investigation, it may seem hopeless to even identify them all. Thankfully, with just a few mouse clicks, these answers are within reach.



HAYIN/DREAMSTIME

The self-guided tour

Truth be told, there are countless ways to survey an image and identify objects within the field. But I find the methods I outline here to be both quick and easy, no matter your experience level.

Diving deep into the cosmos like this allows you to explore the vastness of the universe around us, glimpsing places that human eyes rarely poke around. By following my crash course, as laid out here, you'll soon be a pro at identifying even the most distant objects.

The best way to understand my process is to start with an example: the image shown on the next page. Some of you may recognize the main objects already in this image, but, for this demonstration, let's assume that we have no idea what they are.

First, we upload the image to https://nova.astrometry.net. This website accepts any astronomical image and finds its place on the cosmic map. It calculates the celestial coordinates, complete with a graphically annotated image of the objects in the field. Navigate to the Upload tab at the top of the page, upload the image, and wait for Astrometry.net to return the results, which can take a few moments. Then click "go to results page" beside your newly uploaded image. (See images 2 and 3.)

From here, you can investigate any of

After 20 hours of exposure time, the author captured this image of the Box (Hickson 61), a quartet of galaxies. JASON GUENZEL

the objects in the SIMBAD astronomical database. But let's pick NGC 4175. (If you run into a case where Astrometry.net does not yield any searchable objects in your image, you can still query the galactic coordinates it provides in SIMBAD.)

The SIMBAD address in the sidebar on page 49 will take you to the database landing page. In the middle right of this page is the basic search tool. Type our object identifier, "NGC 4175," into the search bar and hit Enter. Now, let's learn a bit about this galaxy by diving into the results page (image 4).

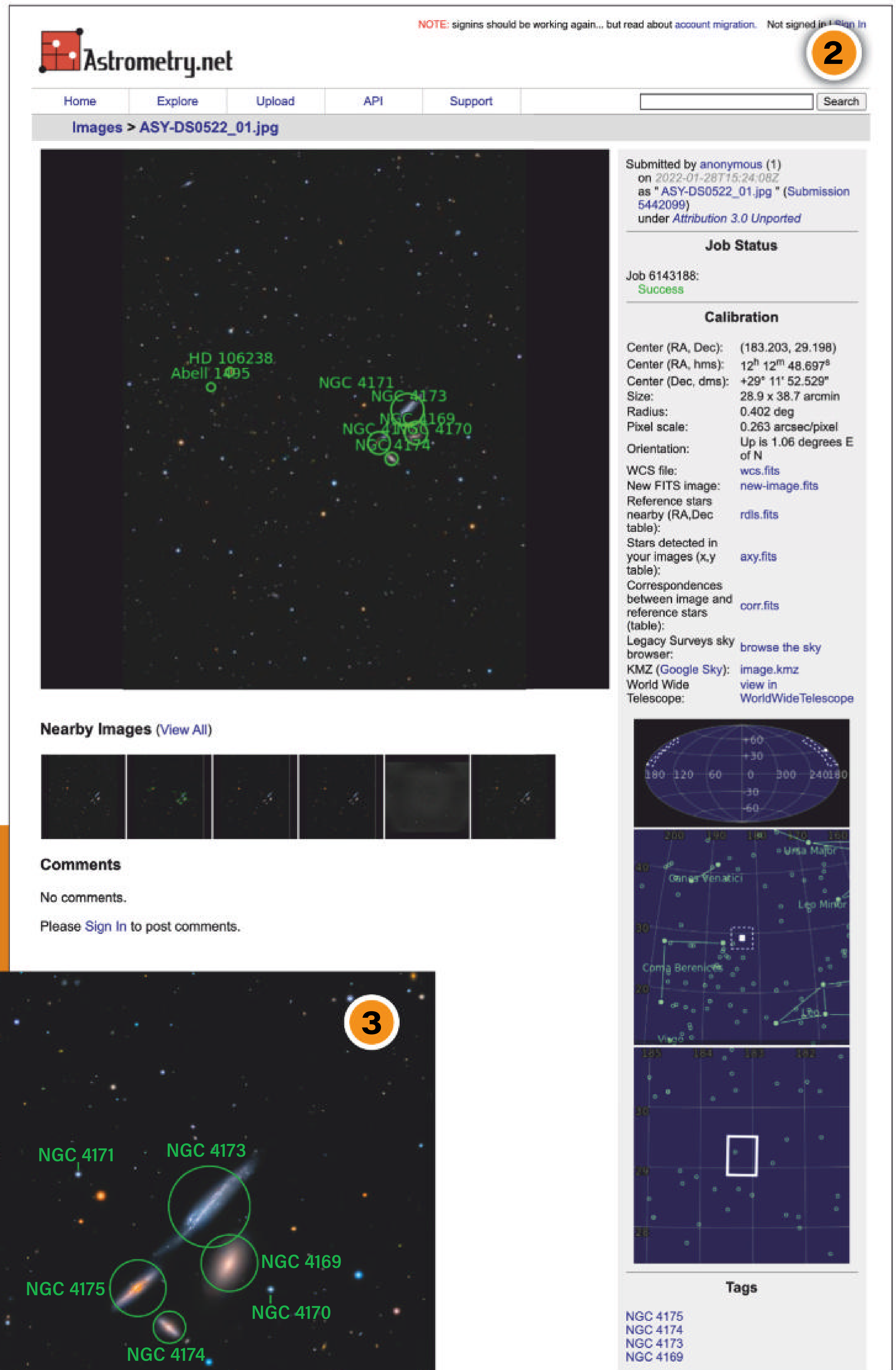
Right off the bat, the header title "Active Galaxy Nucleus" tells us something interesting. The core of NGC 4175 falls under a broad category containing some of the most luminous sources of electromagnetic radiation in the universe. These are the actively feeding supermassive black holes at the centers of massive galaxies. Looking down through the SIMBAD table, we get further information regarding coordinates,

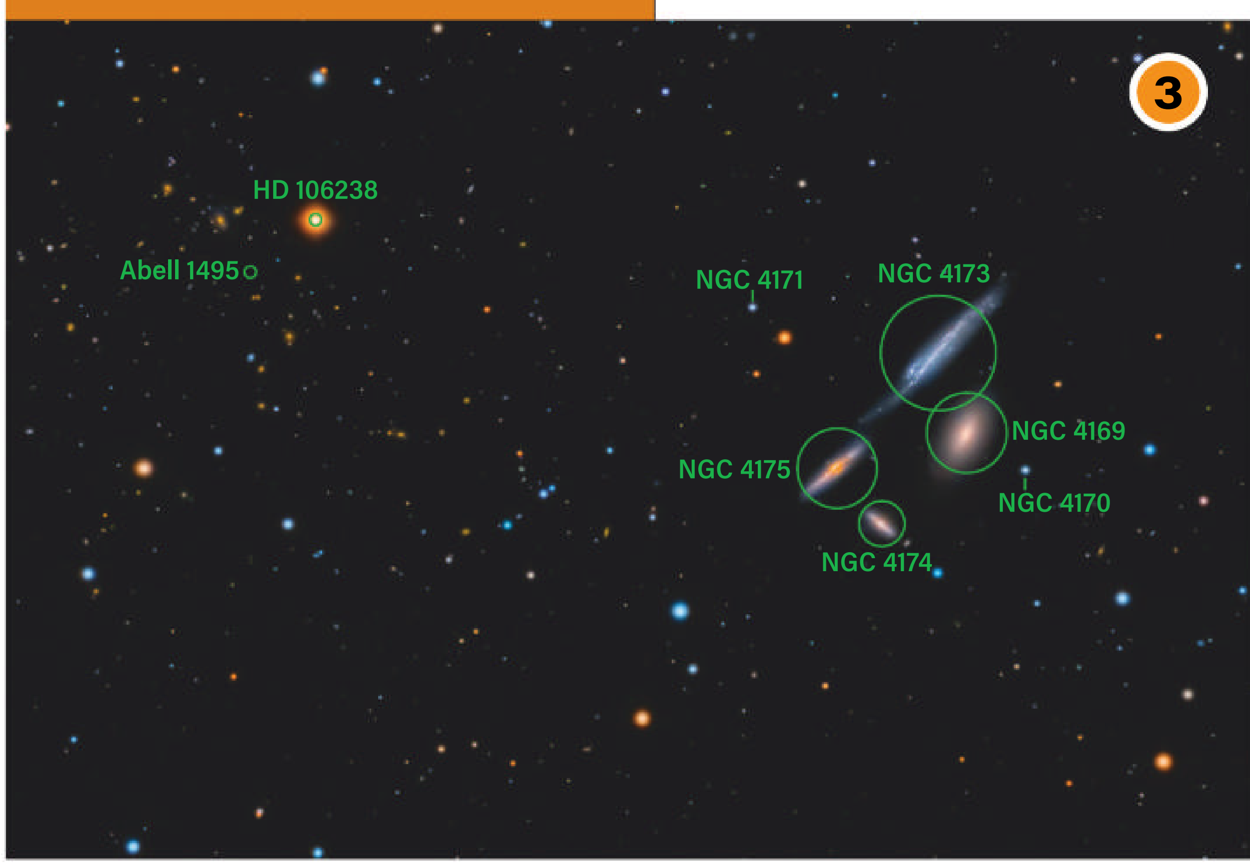
redshift (distance and velocity), size, orientation, morphology, brightness, and much more. To dig a bit deeper still, scroll down to External Archives and click the link to NED, as highlighted in the image. (Note that the site can take a few moments to load your results. If it's taking too long, try clicking the blue Go button.)

On NED, we find much of the same information, but there are a few extra tidbits to pay attention to. Clicking the Redshifts tab (as demonstrated in image 5) and scrolling down reveals a light travel time of 0.201 Gyr, or giga-year, where 1 Gyr is equivalent to 1 billion years. This corresponds to a distance of 201 million light-years.

If we go back to SIMBAD and take the same approach to explore the other members of the Box group, we learn they are not all physically associated. The three main galaxies of the cluster are all at roughly the same distance — NGC 4169 at 195 million light-years,

RIGHT and BELOW: After you upload your image to Astrometry.net, you will see a page similar to this with images annotated in the field. ASTROMETRY.NET; JASON GUENZEL





NGC 4174 at 205 million light-years, and NGC 4175 at 201 million light-years — and are thus likely neighbors in space. NGC 4173, on the other hand, is only 67 million light-years away, meaning it is actually a foreground object.

The above approach will return much more information than many people would care to tease through. But let's assume NGC 4175 intrigued us the most, so we go back to the galaxy's SIMBAD page and move on to the next step. In particular, let's look at the sky survey image in the upper right. Notice that above that image, we have a button displaying the option to "query around" the object (image 4).

Clicking that button takes us to a new page showing an object list on the left and an annotated sky survey image

THE TOOLS AND PROCESS

The best part about these websites is that they require no additional software, are free to use, and, with a little work, can become second nature to you.

Astrometry.net
http://nova.astrometry.net/

SIMBAD (Set of Identifications, Measurements, and Bibliography for Astronomical Data)
http://simbad.u-strasbg.fr/

Aladin Sky Atlas
https://aladin.u-strasbg.fr/

NED (NASA/IPAC Extragalactic Database)
http://ned.ipac.caltech.edu/

A BASIC OUTLINE OF THE PROCESS:

1 If you don't know the identity of the object in question, upload the image to nova.astrometry.net/upload, which will find a match between the stars in your image and those in an astronomical catalog using a method known as plate solving. After a few moments, the website will output the object's name. If you already know the object's name or designation, you can skip this step.

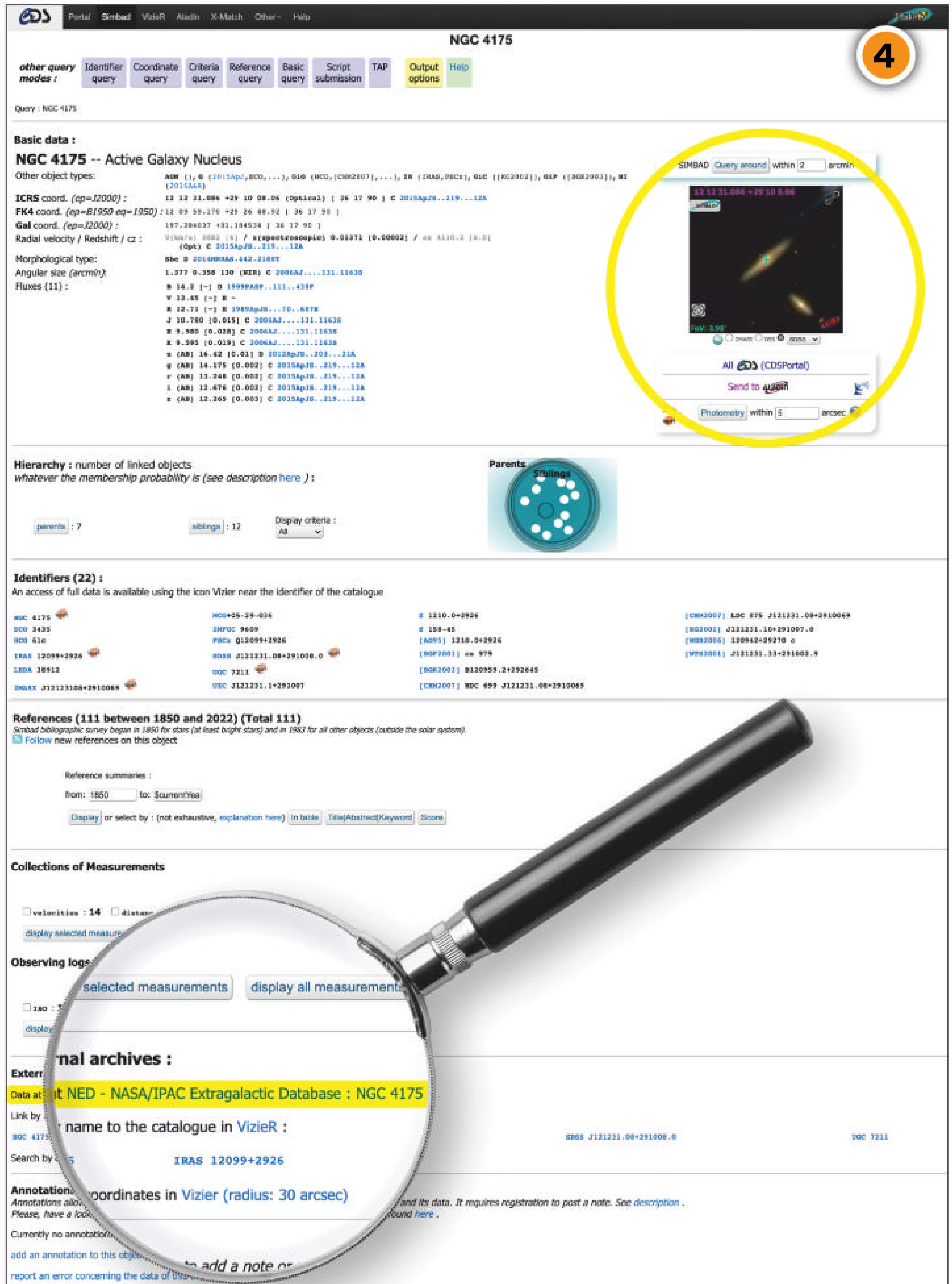
2 Query SIMBAD for the object's properties. *Optional*: Follow links to other databases for even more information.

3 Survey the surrounding area using SIMBAD's "query around" feature to find if there are any more objects hidden in your image.

4 Explore Aladin's sky survey image and the SIMBAD table. Find an object of interest.

5 Click on that object in the Aladin image, which will open up to the SIMBAD page for detailed information, including its properties and links to external databases.

6 For the most distant targets, it may be useful to search for them on NED as well.



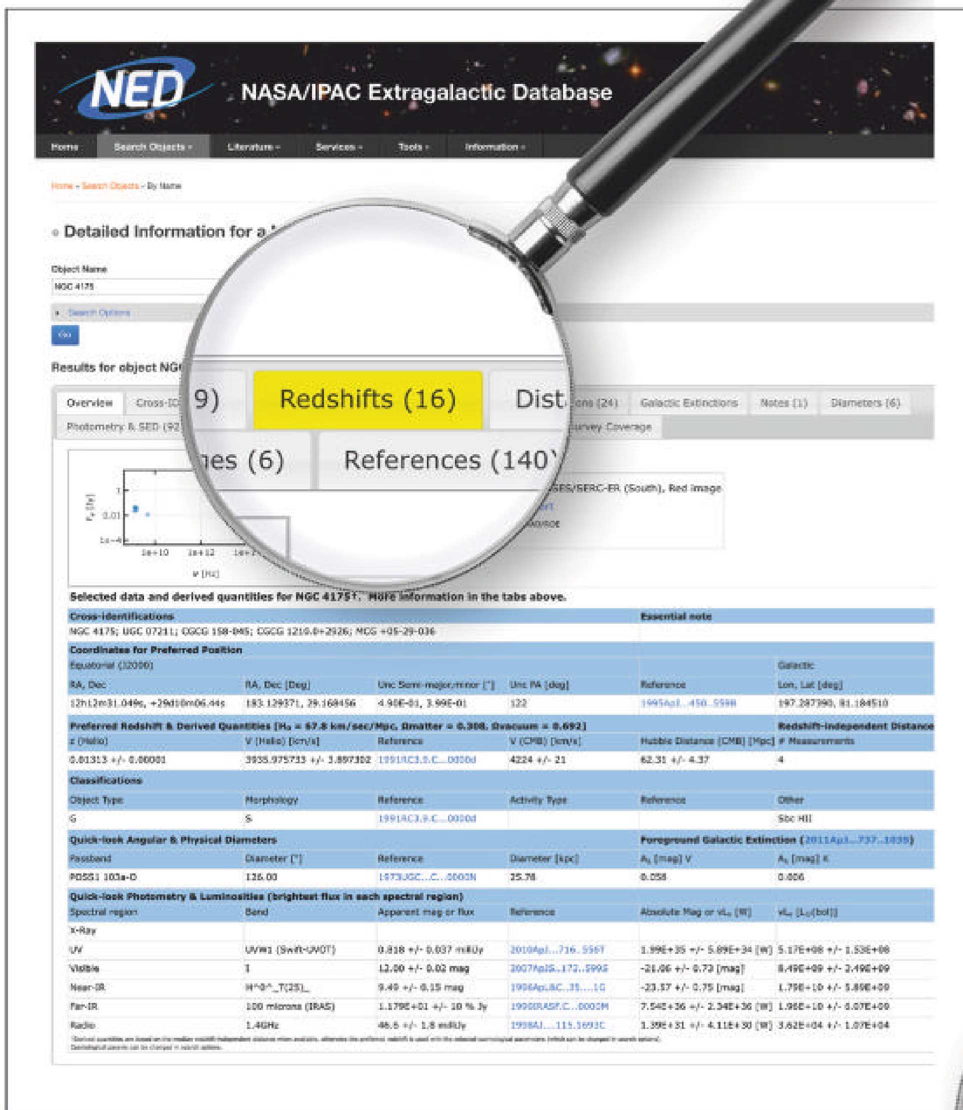
IPAD: HAIYIN/DREAMSTIME. MAGNIFYING GLASS: ANTON STARIKOV/DREAMSTIME

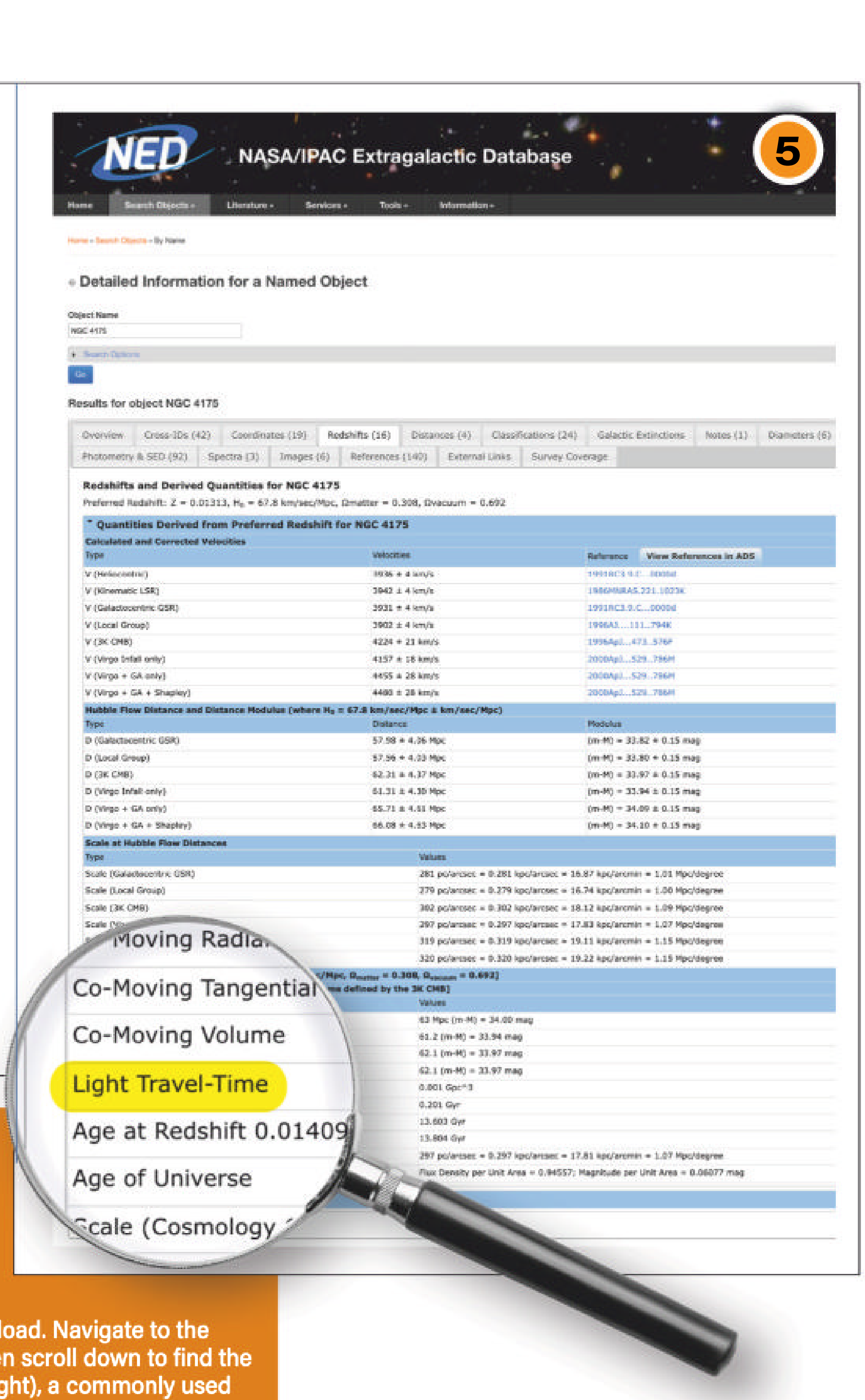
After you search for the object in SIMBAD, a webpage similar to the one above will load. From here you can navigate directly to NED (lower left) or use the Aladin sky atlas (upper right). SIMBAD

When you are visually comparing your image side by side with a sky survey, it may help to rotate your shot to match the default north-up orientation. To be more exact (though not required), Astrometry.net provides the calculated angle of your image under Orientation. You can then use this information to rotate your image exactly to north-up in a photo editor.

on the right, known as the Aladin Lite viewer (image 6). You can hover over objects in the table to turn the location marker green on the image, or vice versa. By default, the list is sorted by the angular distance from the original object you queried. The Otype column shows the classifications of these objects. Clicking on the column header will provide a key as to what these codes mean. One of my favorite objects are quasi-stellar objects, or QSOs, which this image happens to contain. (QSOs, also known as quasars, are the most energetic and distant type of active galactic nucleus — which, you'll remember, is a broad category to which NGC 4175 also belongs.)

To see how far away the object is, click on the QSO identified in the table, 2XMMi J121226.7+291117, and its SIMBAD page pops up. There we can see that SIMBAD does identify it as a





ABOVE: Click on "NED - NASA/IPAC Extragalactic Database : NGC 4175" on the SIMBAD page, and the left webpage will **load. Navigate to the "Redshift" tab and then scroll down to find the "Light Travel Time" (right), a commonly used** measure of distance. NED

COMMON ASTRONOMY UNITS

While looking through these websites, you may come across some measurements and units that you aren't familiar with. Here are a list of the most common ones:

Light-years (ly)
5.8 trillion miles
(9.4 trillion km)

Megayears (Myr)
1 million years

Gigayear (Gyr)
1 billion years

Parsecs (pc)
3.26 light-years

Kiloparsecs (kpc)
1,000 parsecs

Megaparsecs (Mpc)
1 million parsecs

quasar. Then, use the same process as before to navigate to NED. (It's important you use the same process outlined above, as simply copying and pasting 2XMMi J121226.7+291117 into NED will return an error.) When the NED page loads, navigate to the redshift tab and scroll down to light travel-time, and we find that it has a distance of 9.2 billion light-years. Not too bad for a backyard telescope!

Expanding the search

Let's explore a bit more. Backing up again to NGC4175's SIMBAD page (image 4), above the Aladin Lite viewer, you can expand the search radius of the "query around" tool. Instead of the default 2' search, we can increase it out to 30' (image 7). At this point, we are encompassing the entirety of my original image. And wow, is our work cut out for us — 482 objects are listed and shown on the map!

Looking at my image, I'm intrigued by all those fuzzy blobs around the brightest star in the field. Astrometry.net identifies these as belonging to Abell 1495. We can either search that catalog number in SIMBAD, or simply pan and zoom with the Aladin Lite map and click on the object. (Note that SIMBAD shortens Abell to ACO if you use the latter method.)

On its SIMBAD page, under Hierarchy, we see that Abell 1495 is a cluster of galaxies with 36 "children," or probable members. Clicking the children link pulls up a list, along with the probability that each is a member.

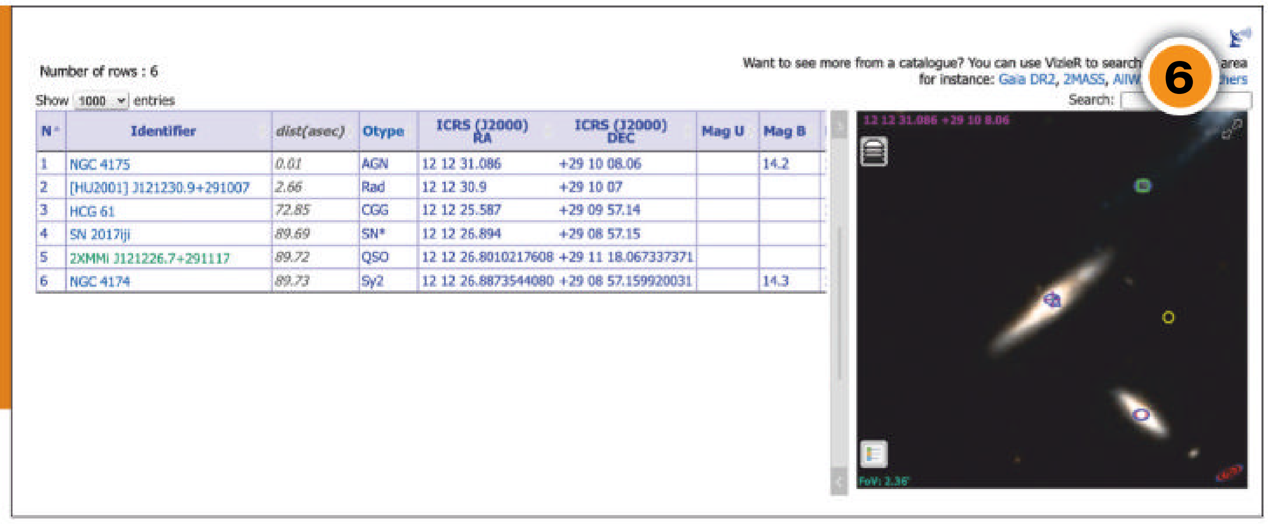
Returning to SIMBAD's ACO 1495 page, if you query out to about 3', we can identify two other fuzzy blobs in the area. Sorting the table by visual magnitude (mag V), we see that the bright star is HD 106238 and the bright spot to its left is 2MASX J12132824+2915253. SIMBAD labels this magnitude 16 object as the "brightest galaxy in a cluster." The available information here tells us we are inspecting an enormous elliptical galaxy over 300,000 light-years across (roughly three times the Milky Way's diameter).

You can repeat this methodology for any object of interest in this field or any other field you wish to explore.

TOP: A 2-arcminute query around NGC 4175 using the Aladin sky survey shows six objects, including a QSO (quasar). SIMBAD

MIDDLE: A 30-arcminute search around NGC 4175 returns 482 objects. SIMBAD

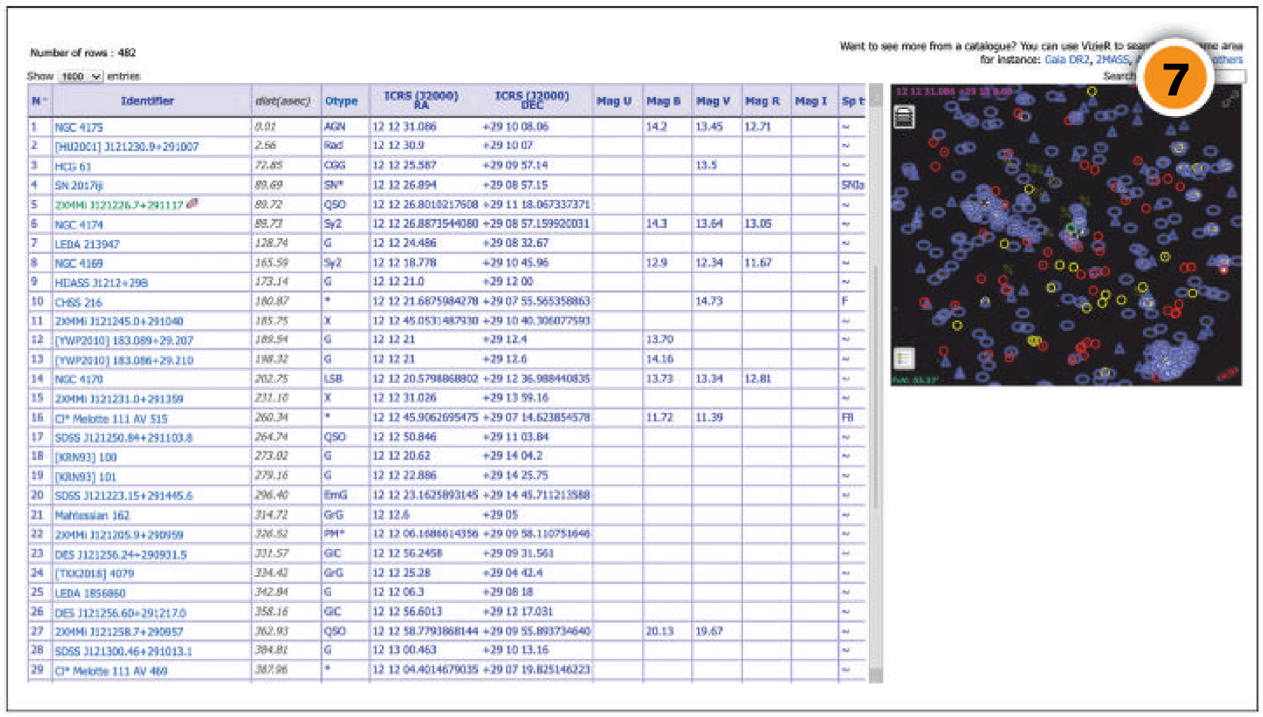
BOTTOM: You may find a number of hidden objects in your images. I've annotated this image with some of the ones I found most interesting after using these methods. JASON GUENZEL



Number of rows : 6

Show 1000 entries

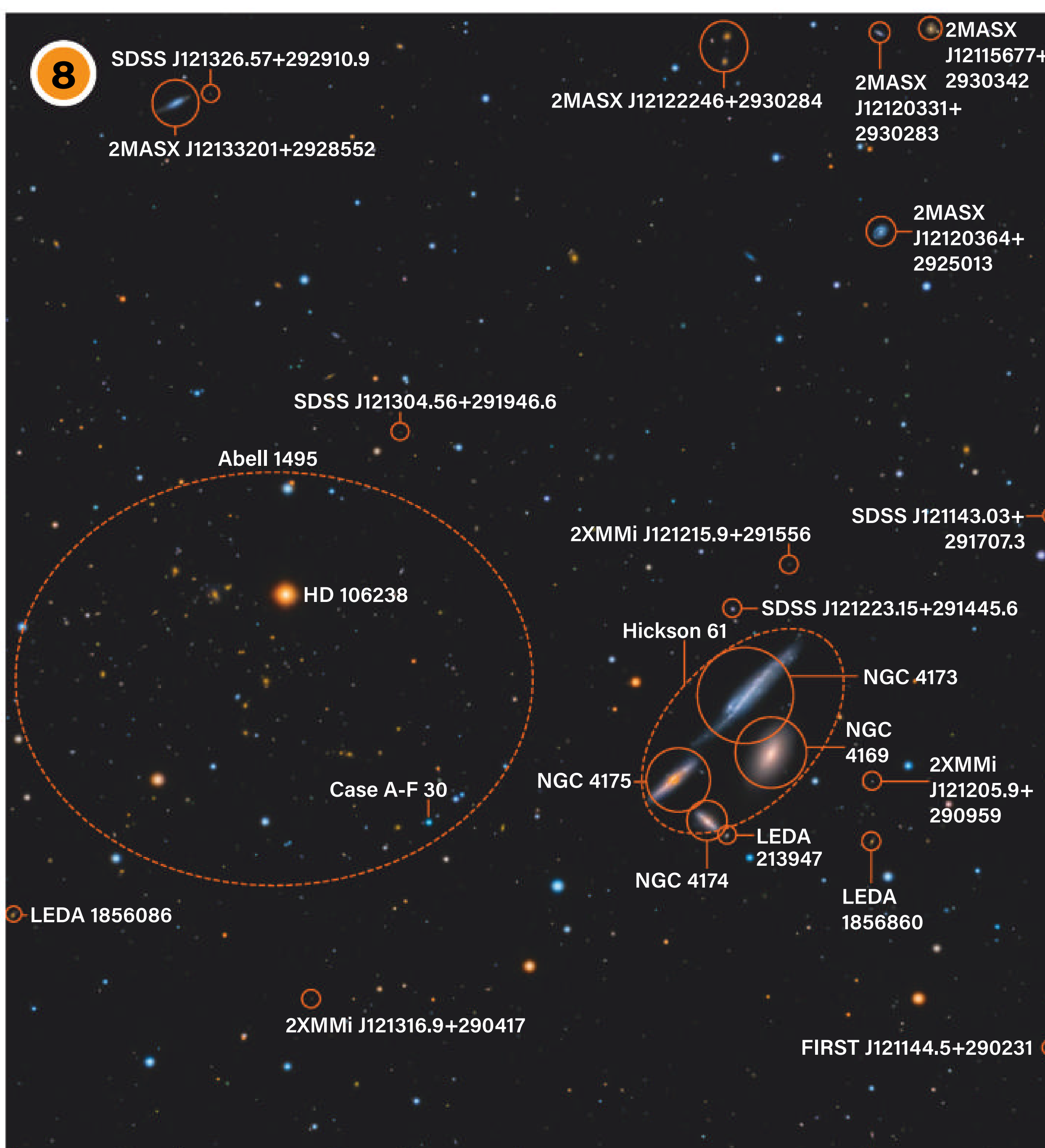
N°	Identifier	dist(asec)	Otype	ICRS (J2000) RA	ICRS (J2000) DEC	Mag U	Mag B
1	NGC 4175	0.01	AGN	12 12 31.086	+29 10 08.06		14.2
2	[HU2001] J121230.9+291007	2.66	Rad	12 12 30.9	+29 10 07		
3	HCG 61	72.85	CGG	12 12 25.587	+29 09 57.14		
4	SN 2017iji	89.69	SN*	12 12 26.894	+29 08 57.15		
5	2XMMi J121226.7+291117	89.72	QSO	12 12 26.8010217608	+29 11 18.067337371		
6	NGC 4174	89.73	Sy2	12 12 26.8873544080	+29 08 57.159920031		14.3



Number of rows : 482

Show 1000 entries

N°	Identifier	dist(asec)	Otype	ICRS (J2000) RA	ICRS (J2000) DEC	Mag U	Mag B	Mag V	Mag R	Mag I	Sp t
1	NGC 4175	0.01	AGN	12 12 31.086	+29 10 08.06		14.2	13.45	12.71		~
2	[HU2001] J121230.9+291007	2.66	Rad	12 12 30.9	+29 10 07						~
3	HCG 61	72.85	CGG	12 12 25.587	+29 09 57.14			13.5			~
4	SN 2017iji	89.69	SN*	12 12 26.894	+29 08 57.15						SNIa
5	2XMMi J121226.7+291117	89.72	QSO	12 12 26.8010217608	+29 11 18.067337371						~
6	NGC 4174	89.73	Sy2	12 12 26.8873544080	+29 08 57.159920031		14.3	13.64	13.05		~
7	LEDA 213947	128.74	G	12 12 24.486	+29 08 32.67						~
8	NGC 4169	165.59	Sy2	12 12 18.778	+29 10 45.96		12.9	12.34	11.67		~
9	HIDASS J1212+298	173.14	G	12 12 21.0	+29 12 00						~
10	CHSS 216	180.87	*	12 12 21.6875984278	+29 07 55.565358863			14.73			F
11	2XMMi J121245.0+291040	185.75	X	12 12 45.0531487930	+29 10 40.306077593						~
12	[YWP2010] 183.089+29.207	189.54	G	12 12 21	+29 12.4		13.70				~
13	[YWP2010] 183.086+29.210	198.32	G	12 12 21	+29 12.6		14.16				~
14	NGC 4170	202.75	LSB	12 12 20.5798868802	+29 12 36.988440835		13.73	13.34	12.81		~
15	2XMMi J121231.0+291359	231.10	X	12 12 31.026	+29 13 59.16						~
16	Cl* Melotte 111 AV 515	260.34	*	12 12 45.9062695475	+29 07 14.623854578		11.72	11.39			FB
17	SDSS J121250.84+291103.8	264.74	QSO	12 12 50.846	+29 11 03.84						~
18	[KRN93] 100	273.02	G	12 12 20.62	+29 14 04.2						~
19	[KRN93] 101	279.16	G	12 12 22.886	+29 14 25.75						~
20	SDSS J121223.15+291445.6	296.40	EmG	12 12 23.1625893145	+29 14 45.711213588						~
21	Mahtessian 162	314.72	GrG	12 12.6	+29 05						~
22	2XMMi J121205.9+290959	326.52	PM*	12 12 06.1686614356	+29 09 58.110751646						~
23	DES J121256.24+290931.5	331.57	GiC	12 12 56.2458	+29 09 31.561						~
24	[TKK2018] 4079	334.42	GrG	12 12 25.28	+29 04 42.4						~
25	LEDA 1856860	342.84	G	12 12 06.3	+29 08 18						~
26	DES J121256.60+291217.0	358.16	GiC	12 12 56.6013	+29 12 17.031						~
27	2XMMi J121258.7+290957	362.93	QSO	12 12 58.7793868144	+29 09 55.893734640		20.13	19.67			~
28	SDSS J121300.46+291013.1	384.81	G	12 13 00.463	+29 10 13.16						~
29	Cl* Melotte 111 AV 469	387.96	*	12 12 04.4014679035	+29 07 19.825146223						~



Digging deeper

The process outlined here is generally sufficient to investigate the brighter and larger objects in a field, but it does not define the bounds of what you can explore. Aladin offers powerful tools to continue to drill down into the most remote corners of an image by linking out to the additional catalogs in the VizieR utility. VizieR is a photometry tool that provides users an easy visualization of points around a given position or object. From here, the journey gets a bit cumbersome for a casual explorer, but it is still possible. Do note that the aforementioned resources pull information from various source catalogs. As a result, at times you may find disagreement in certain properties, incomplete object information, or changing results over time as the data are continually refined when new surveys are published. This means what is true one month might be outdated the next.

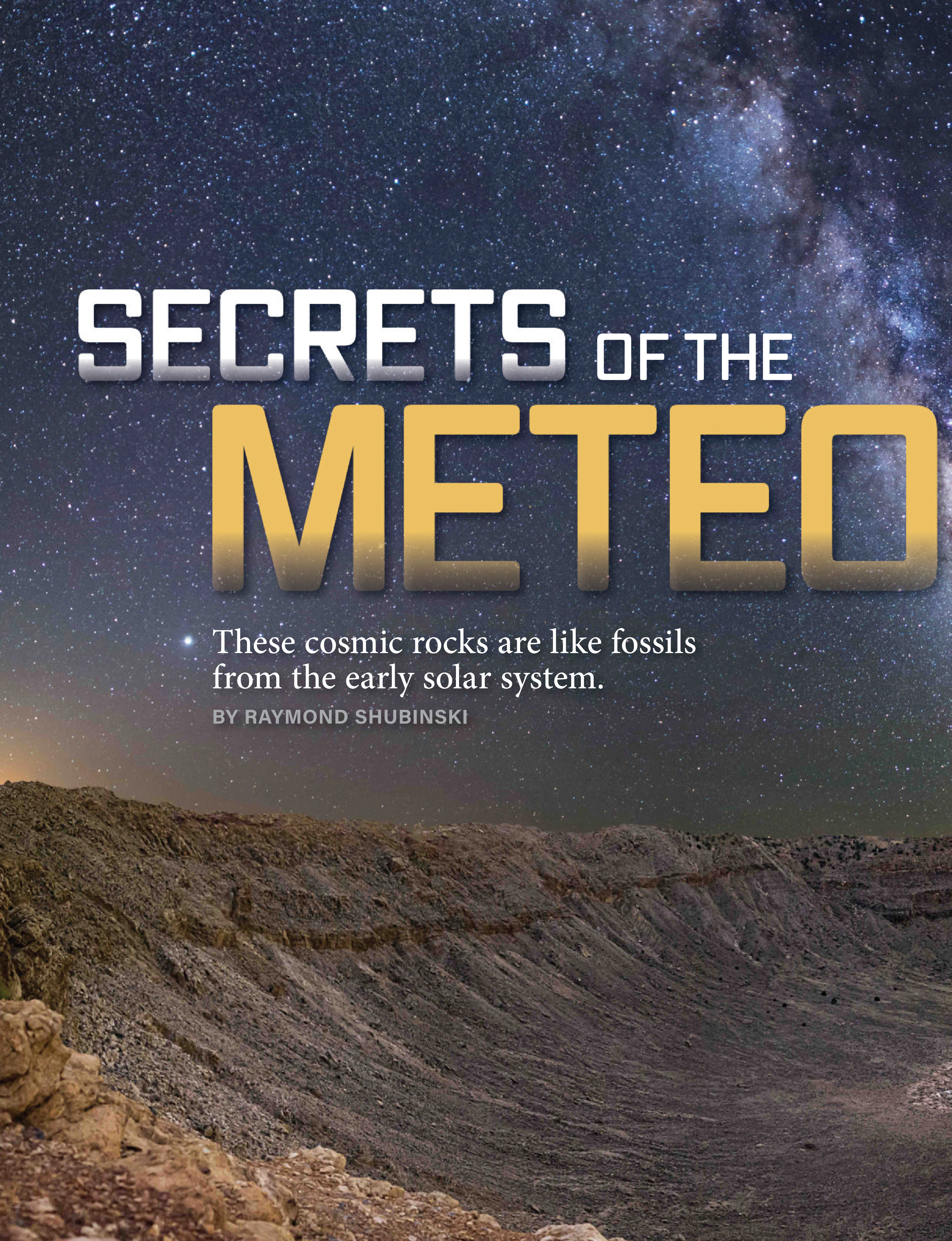
Though it is rare to fully strike out on identifying an object, available data definitely become sparse as smaller and fainter objects are queried. In that case, consider that you are reaching the limits of human exploration into the cosmos. These little smudges are simply assigned a numerical identifier based on their coordinates, with only a small amount of cataloged photometric data available from a sky survey. Much like early explorers who traveled off the map, we are probing the edges of our knowledge about these realms. And even the backyard observer can reach out through the cosmos to the very frontiers of human exploration.

Jason Guenzel *is an avid backyard astrophotographer based in Michigan. His work can be found on major social media platforms, including @TheVastReaches and www.thevastreaches.com.*

SECRETS OF THE METEO

These cosmic rocks are like fossils from the early solar system.

BY RAYMOND SHUBINSKI



RITES

Roughly 60,000 years ago, a meteorite smashed into the Arizona desert, forming Meteor Crater. Recovered fragments of this meteorite played a key role in determining the age of Earth.
JOHN VERMETTE

IN JULY 1969, THE CREW OF THE APOLLO 11

BROUGHT BACK NEARLY 48 POUNDS (22 KILOGRAMS) OF PRISTINE LUNAR ROCKS FROM THE MOST INCREDIBLE — AND EXPENSIVE — ROCK-COLLECTING EXPEDITION IN HISTORY. NASA HAD STATE-OF-THE-ART CLEAN LABORATORIES AND EQUIPMENT READY TO ANALYZE THESE SAMPLES IN UNBELIEVABLE DETAIL.

IN THE SAME YEAR, HOWEVER, NATURE ALSO PROVIDED SEVERAL TONS OF COSMIC DEBRIS FOR FREE.

In February 1969, a massive meteorite rained a couple of tons of stones on the Mexican town of Allende, not far from the Texas border. And in September, over 200 pounds (90 kg) of cosmic material fell near the town of Murchison in Victoria, Australia, about 100 miles (160 kilometers) north of Melbourne.

The timing of these events was perfect. Geologists, chemists, and other scientists were better prepared to coax secrets from these otherworldly rocks than at any other time in history. For most of human history, the origin of these stones was an enigma. But by the mid-20th century, there was no doubt that these rocks had a cosmic origin. The bits of detritus that found their way to Earth in 1969 marked a milestone in our quest to unlock their mysteries.

EARLY VISITORS

Humans have seen rocks falling from the sky for thousands of years. One of the earliest potential recorded accounts dates to 1478 B.C., when, according to the Parian Chronicle, a "thunderstone" fell on the island of Crete. In 465 B.C., the Greek poet Pindar saw a meteorite land not far from the hill where he was sitting. And in 1492, a stone fell from the sky just outside the city of Ensisheim, France, becoming a marvel in Europe for centuries. It was widely believed that these stones formed in clouds and, when heavy enough, simply fell to Earth. Where else could these ordinary-looking rocks have originated?

But at the start of the 19th century, a number of events came together that changed the way people understood and studied these objects. On April 26, 1803, the villagers of L'Aigle, France, saw and heard an amazing fall. Over 3,000 stones were recovered, making the event impossible to ignore. Just two years earlier, the astronomer Giuseppe Piazzi had discovered the asteroid Ceres, clearly showing that there were objects other than planets circling the Sun. Geologists and chemists also were making great strides in understanding terrestrial rocks and developing techniques to reveal their structure.

Around the year 1800, the British chemist Edward Charles Howard acquired several suspected meteorites, including examples of each of the three main meteorite types recognized today: stony, iron, and stony-iron. Howard was the first to dissect and subject these extraterrestrial stones to chemical analysis. In 1802, he reported that all three types of meteorites had a high level of nickel, a composition unlike anything seen before in terrestrial rocks.

Two years later, a British mineralogist, William Thomson, tried polishing an iron meteorite with nitric acid, revealing a striking crystalline pattern. These became known as Widmanstätten lines after Count Alois von Beckh Widmanstätten, who made a similar discovery in 1808. No such pattern is seen in iron mined on Earth. These two men had discovered the ancient frozen crystal structure of iron meteorites, unchanged for billions of years.

Leaping forward to the 20th and 21st century, meteorite research progressed thanks to new techniques and equipment used to study these cosmic visitors. These investigations included,

Roughly 30 tons of material have been recovered from the Canyon Diablo meteorite, the object that created Meteor Crater, including the fragment shown here. BRUCE C. COOPER

Ancient Egyptians used meteoritic iron in certain prized artifacts, such as the Gerzeh beads (left) and Tutankhamun's dagger (right). Ancient Egyptians called the material "bi-a-n-pt," meaning "iron from the sky." MANCHESTER MUSEUM; DANIELA COMELLI

unexpectedly, an archaeological mystery. In 1911, British archaeologist Gerald Avery Wainwright discovered necklace beads made of iron in a 5,500-year-old Egyptian cemetery in Gerzeh, about 44 miles (70 km) south of modern Cairo. And when the British archaeologist Howard Carter opened the tomb of the pharaoh Tutankhamun in 1922, he found — among many beautiful artifacts — a magnificent ceremonial dagger with a gold handle and an iron blade.

The presence of these iron artifacts was conspicuous, since during Tutankhamun's life 3,300 years earlier, Egyptians had not yet mastered the art of smelting iron and were still using bronze for their weapons. Chemical tests indicated a high level of nickel in the Gerzeh beads and Tutankhamun's blade, pointing to an extraterrestrial origin. However, in the 1980s, some archaeometallurgists suggested that nickel-rich iron ores found on Earth could have been the source of these artifacts.

Finally, in 2016, researchers reported in *Meteoritics and Planetary Science* a noninvasive examination of King Tutankhamun's iron dagger that confirmed its meteoritic origins. The team used a portable X-ray fluorescence spectrometer, which looks at the wavelengths of fluorescing elements to determine their abundance. The researchers found the dagger was nearly 11 percent nickel and around 0.6 percent cobalt — whereas terrestrial iron produced before the 19th century rarely exceeds 4 percent nickel. They then compared this to iron meteorites found within a 1,200-mile (1,930 km) radius of Tutankhamun's tomb and found a possible match — the Kharga meteorite, found in 2000 near the city of Marsa Matruh, Egypt. Using similar tests, the Gerzeh beads were shown in 2013 to be from an iron meteorite.

DIGGING IN

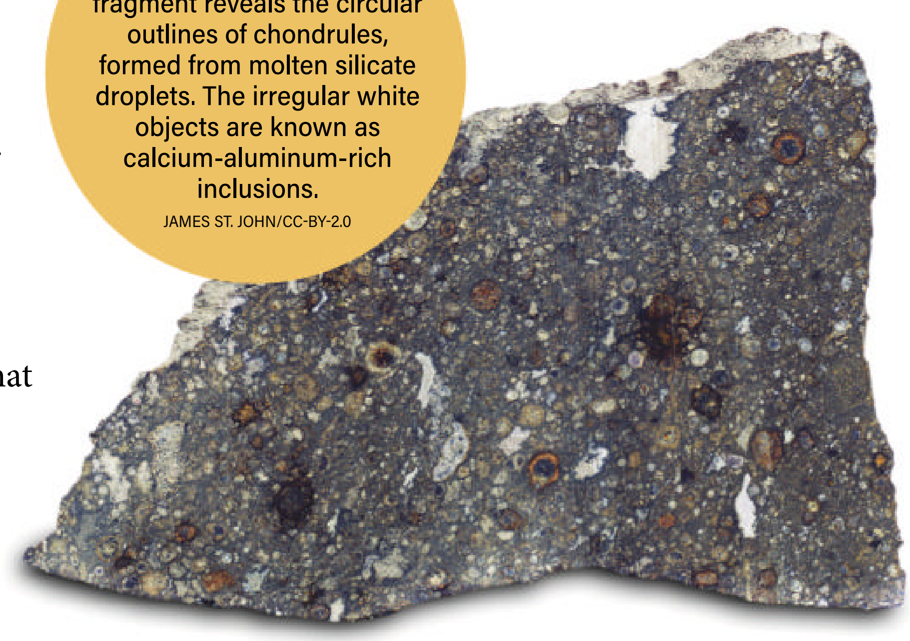
One of the primary devices used to study meteorites is the mass spectrometer. This instrument can detect atoms of specific elements and measure the abundance of their isotopes — atoms of the same element with the same number of protons but with differing numbers of neutrons. Measuring the abundances of various isotopes can be used to date samples. For example, carbon-14 is widely used to determine the age of organic material. Isotope analysis can also be used to dissect and study the atomic components of meteorites.

There is a downside: The sample is destroyed in the process. To probe a sample with a mass spectrometer, a small piece of meteorite is placed in a chamber, where it is heated until it vaporizes. The gas is then ionized, and the resulting ions are accelerated with an electric or magnetic field. Since different isotopes have different masses, they are deflected by differing amounts, indicating their relative abundance. This technique can be used to reveal some of the secrets locked up in meteorites.

The massive fireball that exploded over Allende in February 1969 provided plenty of material, scattering thousands of stones over a huge area. Over 2 tons were recovered, giving researchers — already primed by the impending Apollo missions — an abundance of material to investigate. As a result, the Allende meteorite has become one of the most studied meteorites in history.

The Allende meteorite is a rare primitive meteorite known as a carbonaceous chondrite. It is rich in carbon in the form of graphite, organic compounds, water, and amino acids. When sliced open, its interior is black and filled with beautiful white, snowflakelike inclusions. When analyzed with a mass spectrometer, these white specks were found to be the oldest known minerals in the solar system, an estimated 4.567 billion years. The calcium-aluminum materials had to form out of material from the nebula that birthed the Sun, and at extremely high temperatures that could only be found in the early solar system. Studies using mass spectrometers also showed oxygen isotopes similar to those found in the Sun. The Allende meteorite is now considered one of the oldest objects ever found on Earth.

When the Murchison meteorite fell just two months after Apollo 11 returned from the Moon, researchers had yet another unusual carbonaceous



This cross-section of an Allende meteorite fragment reveals the circular outlines of chondrules, formed from molten silicate droplets. The irregular white objects are known as calcium-aluminum-rich inclusions. JAMES ST. JOHN/CC-BY-2.0

MAP BY *ASTRONOMY*: ROEN KELLY

COSMIC VISITORS

METEORITE FALLS HAVE BEEN RECORDED THROUGHOUT HUMAN HISTORY, YIELDING WONDER, CONFUSION — AND KNOWLEDGE. HERE ARE JUST A FEW RECOVERED SPACE ROCKS THAT HAVE PROVEN HISTORICALLY OR SCIENTIFICALLY SIGNIFICANT.

ALLENDE (1969)
With over 2 tons of material recovered, this meteorite is one of the best studied in history.

MURCHISON (1969)
In 2020, scientists reported that this meteorite contains grains that are older than the Sun.

ENSISHEIM (1492)
The main mass of this meteorite is on display in the city's Regency Museum.

L'AIGLE (1803)
The L'Aigle meteorite was pivotal in establishing the extraterrestrial origin of such stones.

CANYON DIABLO *(60,000 years ago)*
Clair Cameron Patterson used samples from this meteorite to determine the age of the Earth.

KHARGA *(impact date unknown, discovered 2000)*
King Tutankhamen's iron dagger may have been made from a fragment of this meteorite.

MOROKWENG *(impact 145 million years ago, fragment found 2004)*
Researchers drilling into the 44-mile-wide (70 kilometers) Morokweng impact crater in 2004 unexpectedly found a soccer-ball-sized chunk of the original asteroid. Previously, scientists had thought that large impactors would mostly vaporize on impact.

ALLAN HILLS 84001 *(impact date unknown, discovered 1984)*
Recovered from the Allan Hills of Antarctica, this rock was originally a chunk of Mars. It achieved notoriety in 1996 when a team of researchers argued some features could be the remnants of fossilized microbial life — a claim ultimately rejected by most astrobiologists. NASA/JSC

CHELYABINSK (2013)
The 66-foot-wide (20 meters) asteroid that exploded over Chelyabinsk, Russia, in 2013 was the largest known object to enter Earth's atmosphere since the Tunguska event in 1908. SVEND BUHL/METEORITE RECON/CC BY-SA 3.0

FUKANG (*impact date unknown; discovered 2000*)
Found by a hiker, the Fukang meteorite is considered one of the most beautiful ever found. When cut into slices, embedded fragments of olivine transmit light like a golden stained-glass mosaic. WOLFGANG SAUBER/CC BY-SA 3.0

CAMPO DEL CIELO *(impact 4,500 years ago)*
The fireball and impact of this large meteorite — one fragment weighs 37 tons — may have been witnessed by Aboriginal people and transmitted as oral historical knowledge. In 1576, Argentinian authorities documented a fragment after investigating reports of locals wielding iron weapons forged from stones that had fallen in an area they called the Field of the Sky. HOWARDITES METEORITES/CC BY-SA 4.0

chondrite meteorite to study. Like the Allende meteorite, the Murchison is made of a kind of cosmic gravel called chondrules, which coalesced in the earliest stage of the solar system's birth.

Researchers are now tracing this story even further back in time by identifying and studying presolar grains of dust — cosmic specks locked in the meteorites that formed even before the Sun did. A 2020 study in *Proceedings of the National Academy of Sciences* reported presolar silicon carbide particles in the Murchison meteorite — remnants of stardust up to 7 billion years old!

A 2020 study in *Physical Review Letters* offers the potential to learn more about presolar grains. The team, led by researchers at the University of Surrey, England, developed a technique using a linear particle accelerator at Argonne National Laboratory in Illinois to trace the paths of gamma rays emitted by reactions involving the isotope argon-34. Using this data, the team calculated the ratios of sulfur isotopes produced in two types of stellar explosions: supernovae, the explosive deaths of aging stars; and novae, thermodynamic explosions of material limited to a star's outer layer. The results could allow scientists to determine whether a particular presolar grain was formed in a supernova or a nova — providing information about the death of stars in the vicinity of our solar system long before it began to form.

THE AGE OF EARTH

None of this information has context without one precise indicator: knowing the age of Earth. From ancient Greek philosophers to 21st-century scientists, humans have always sought to measure the age of our world.

Researchers obtained one key to this mystery during the Manhattan Project, the U.S. research program that unlocked the destructive power of the nuclear bomb. As part of this work, scientists determined the rate of decay for uranium with great precision.

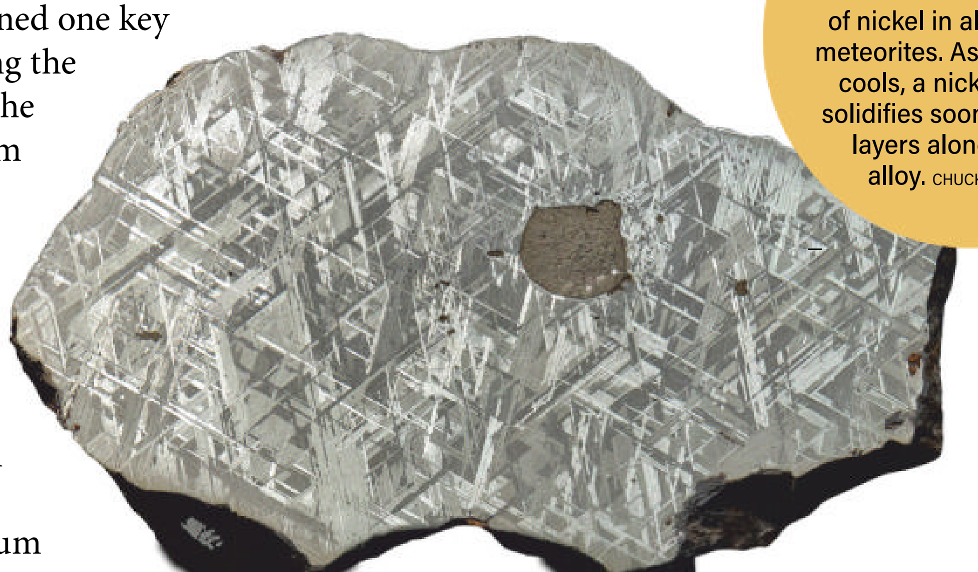
Among the uranium isotopes that naturally occur on Earth are uranium-238 and uranium-235. Both decay into two different isotopes of lead, though at different rates. But trying to measure the abundance of lead isotopes on Earth to find its age does not give a correct answer. It turns out that not all lead on Earth came from decaying uranium. To solve this problem, scientists needed to know how much of each lead isotope existed when the solar system formed — and a meteorite provided the answer.

FROM IRON CRYSTALS TO ANCIENT STARDUST, THE STUDY OF METEORITES HAS UNLOCKED MANY TANTALIZING SECRETS.

In 1948, Clair Cameron Patterson, a Ph.D. student at the University of Chicago, was tasked with investigating the lead concentrations of meteorites. His supervisor, geochemist Harrison Brown, reasoned that iron meteorites would have formed with nearly no uranium, meaning their ratio of lead isotopes would reflect that in the early solar system. Patterson sliced his samples open and found pockets of sulfides, from which he extracted a tiny sample of lead.

But when he tried to measure the lead, he ran into an almost insurmountable roadblock: lead contamination. His dusty laboratory in Kent Hall — one of the oldest buildings on campus — was filled with lead. It was in the solvents he used to dissolve the sample, in the glass flasks he was using, on his hands, and in the air.

It wasn't until Brown accepted a faculty position at Caltech — and took Patterson with him — that Patterson had the funding to build from scratch what was then one of the cleanest laboratories in the world. In 1953, he was finally able to extract a pure sample of primordial lead from a small chunk of the iron Canyon Diablo meteorite, which fell about 60,000 years ago and created the famous Meteor Crater in Arizona. He then vaporized his sample in a mass spectrometer at Argonne and measured the exact ratios of isotopes to find his answer: Earth is 4.55 billion years old.



The intricate, interleaving layers of Widmanstätten patterns are due to differing levels of nickel in alloys found in meteorites. As the meteorite cools, a nickel-rich alloy solidifies sooner and forms layers along the other alloy. CHUCK SUTHERLAND

Patterson's work had far-reaching consequences. He went on to champion the reduction of lead in our environment, most notably in leaded gasoline. And as result of Patterson's efforts, cleanroom laboratory technology was ready for NASA when Moon rocks were brought to Earth. And all of this came about because of a meteorite.

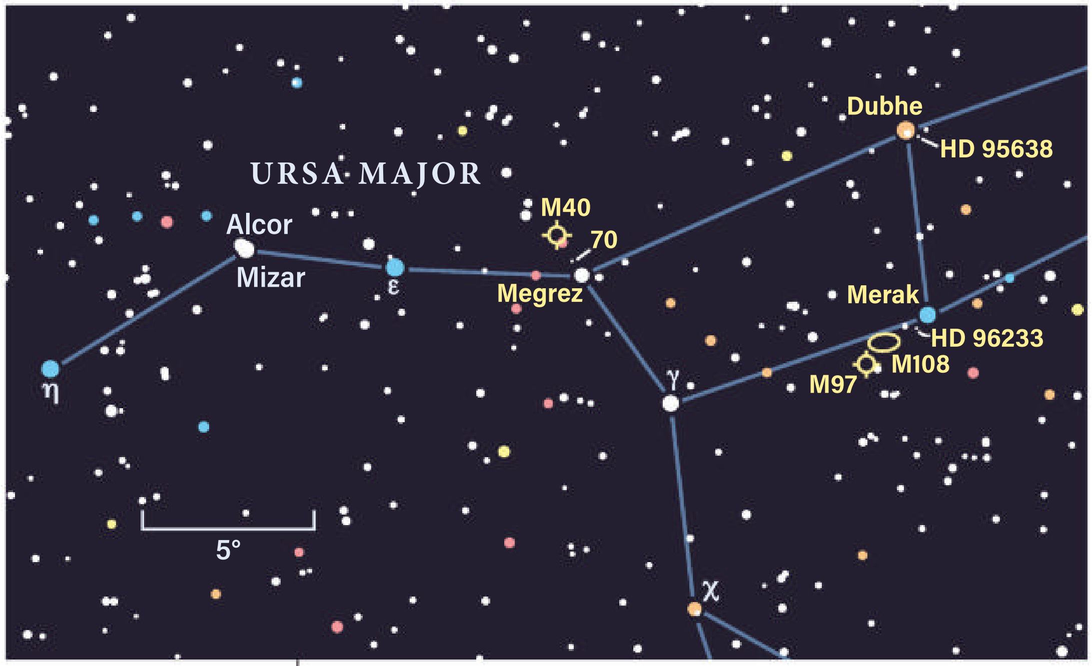
The effort to extract knowledge from these bits of cosmic detritus is far from over. The search is now on for fossilized micrometeorites — rocks that fell to Earth millions of years ago and are now preserved in ancient limestone. (See "Excavating cosmic fossils" in the August 2020 issue for more.) When meteorites streak through the atmosphere, they absorb oxygen. By analyzing these fossilized remains, we can get a glimpse of the ancient atmosphere and how it may have affected life on Earth.

From iron crystals to amino acids and ancient stardust, the study of meteorites has unlocked many tantalizing secrets. The work will continue, and more secrets will be discovered in these celestial visitors.

Raymond Shubinski *is a contributing editor of* Astronomy. *He has an extensive meteorite collection and never fails to say "Wow!" when he sees a bright shooting star.*

Dipping deep

Challenge yourself with these Big Dipper treasures.



Challenge yourself to find the more difficult objects the Big Dipper has to offer.
ASTRONOMY: ROEN KELLY

High in the northern sky this month, we find the best-known pattern of stars in the sky: the Big Dipper. Perhaps spotting it for the first time earned you a scout merit badge. Or maybe, like me, you traced its pattern in the sky during an astronomy unit in grade school. Regardless, pretty much everyone living north of the equator has seen the Big Dipper. But have you uncovered everything it has to offer?

There are several hidden riches buried in and around the Dipper's bowl. Let's begin with **Dubhe** (Alpha [α] Ursae Majoris). Despite its Alpha designation, Dubhe is the second-brightest star in Ursa Major. Raise your binoculars its way and you will see that it is joined by a 7th-magnitude companion sun, HD 95638, to its south. Both lie about the same distance from Earth, some 125 light-years. While many sources list them as a binary pair, they may not actually be close enough to be gravitationally bound. Both are spectroscopic binaries, however.

There are several hidden riches buried in and around the Dipper's bowl.

For those who enjoy a challenge, this month I have three Messier objects for you.

First up, shift your aim from Dubhe to Megrez (Delta [δ] Ursae Majoris), at the bowl's northeast corner. Our target, **M40**, is hiding in the same field of view.

M40 is unlike any other entry in Charles Messier's catalog. While most of the 109 entries are star clusters, nebulae, or galaxies, M40 is an optical double star — two stars widely separated in space that just happen to lie along the same line of sight from Earth.

So, why did Messier include a pair of stars in his catalog of comet lookalikes? The confusion started in 1660, when German astronomer Johannes Hevelius recorded seeing a "nebula above the back" of Ursa Major. Messier searched for Hevelius' nebula but came away empty-handed — at least with respect to that particular target. He did find a pair of faint stars, which became M40.

Nearly 100 years later, Russian astronomer Friedrich Winnecke independently found the same double star, adding it as the fourth listing in his double star catalog. That's why you may also see M40 referred to as Winnecke 4.

With dark skies, I have been able to resolve the two stars in 10x50 binoculars, but with effort. To find them, aim toward Megrez and shift your attention 1° to the northeast, to 6th-magnitude 70 Ursae Majoris. M40 is just a quarter-degree farther northeast. At low magnification, M40 does appear slightly nebulous, which is maybe what Hevelius saw in the first place.

Now, transfer your attention to Merak (Beta [β] Ursae Majoris), at the bowl's southwest corner. We will use Merak as our starting point to the last two challenging Messier objects.

First, try your luck with the edge-on barred spiral galaxy **M108**. Holding steady on Merak, shift your attention 44' southeast to 7th-magnitude HD 96233 and then another 35' to a widespread pair of 9th-magnitude stars. M108 is just east of those stars. You will need pristine conditions, but through binoculars M108 will look like a faint cigar-shaped glow barely visible against the background sky. Your best chance at spotting it is to first secure your binoculars to a separate mount rather than supporting them by hand. Although I have spotted M108 in my 10x50s, it is much easier to identify in my 16x70s and certainly with my 25x100s.

Our final target this month is the planetary nebula **M97**, known as the Owl Nebula. The Owl is perched 48' southeast of M108, beyond a 7th-magnitude star that lies halfway between the two. I have also spotted its gray sphere through my 10x50s under dark skies, but like M108, its surface contrast against the background sky is very low. Use all the tricks at your disposal to see it: Try using averted vision and tapping the barrels lightly once aimed its way. The slight motion sometimes reveals a dim object that is otherwise invisible.

Have a favorite binocular target? Let me know about it, so I can feature it in a future column. Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

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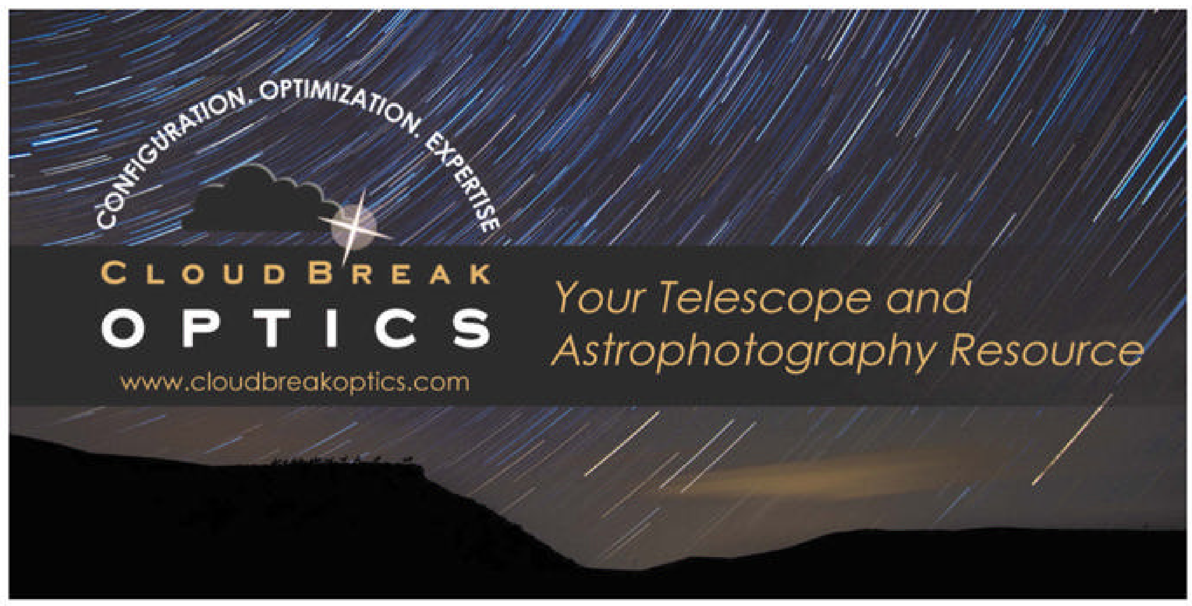
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Snapping your own lunar pics

Even dinosaurs can learn new tricks.

Fellow observer Ted Hauter captured this image of the Moon using a Samsung Galaxy S9 and an Explore Scientific ES127 with a correct image prism diagonal.
TED HAUTER

BY GLENN CHAPLE
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

Astronomically speaking, I'm a dinosaur. I much prefer to explore the night sky with a no-frills telescope while producing eye-to-hand astroimages with pencil and paper.

I have dabbled with primitive astrophotography, but it didn't hold my interest for long. Back in the 1970s, I loaded a 35mm camera with slide film, affixed it to a tripod, and took 20-second timed exposures of the constellations. But I never progressed to attaching camera to telescope and taking pictures of the Moon, planets, and deep-space objects.

Even the arrival of computer-driven telescopes and digital imaging failed to pique my interest. I experimented with imaging using a digital camera and a small telescope, which I documented in my February 2010 column "Astroimaging 101." However, I quickly returned to my old ways the following month with an article titled "Sketching 101."

In early 2011, I was told that the November issue of *Astronomy* would be astroimaging-themed. I panicked. Because I had already written about small-scope imaging with a digital camera, I had to up my game.

My first thought was advanced forms of astroimaging. But there was no way I could afford the hundreds, if not thousands, of dollars towards the equipment — a telescope with an accurate drive, imaging and processing instrumentation, etc. — needed to take the kind of cosmic portraits that appear monthly in *Astronomy*. Even if I could, it would take many months, maybe even years, to master the art.

Then I got an email from Glenn Holland of Marina Del Rey, California, who sent me some impressive images of the Moon taken with his smartphone and an 8-inch Schmidt-Cassegrain scope. Since a smartphone camera is digital, I could revisit the topic from a new viewpoint! While I didn't own a smartphone (technical dinosaur, remember?), my son did. Armed with a 4.5-inch, f/8 Dobsonian-mounted reflector, after half an hour of trial and error, we managed to get a passable image of the Moon. The article — November 2011's "Cellphone imaging" — was successfully completed.

Was I finally inspired to abandon pencil, clipboard and paper, and red-filtered flashlight in favor of a high-tech astroimaging setup? Not really. I still preferred the pure pleasure of eyepiece sketching, which, in my view, provides for an intimate connection to a celestial object.

But the seed had been planted. By late 2016, I had a smartphone of my own. Encouraged by my earlier success with my son, I decided to make nightly smartphone images of the Moon with the 4.5-inch reflector, amassing enough to create a small-scope lunar atlas for my personal use. It was tough going initially. Finding the "sweet spot" between eyepiece and smartphone so that the Moon appeared in the viewscreen was time-consuming. I ended up with a fair number of blurry shots in the first few sessions. But it wasn't long before I had gained a feel for positioning and holding the phone steady as I snapped each picture.

If you've never tried smartphone imaging with a telescope, here are some tips:

1. Stick to the Moon as your primary subject. The planets and deep-sky objects require more sophisticated techniques and equipment.

2. Find and turn off your smartphone's flash — usually depicted by a lighting bolt on the camera. The flash will reflect off the eyepiece, washing out the image.

3. Work with a telescope magnification that's low enough to capture the entire lunar disk in the eyepiece field.

What better souvenir to take home than a personal image of the Moon?

4. Take up to a dozen shots during your first run. Then step aside and examine each for an acceptable image. If none prove suitable, try another run. You'll find with each passing night it takes fewer attempts to get an image you like.

5. Store your images in a secure place — not just on your phone. The best photo management system is the one that works for you, and that you will regularly use.

Smartphone imaging of the Moon is also an activity you can share with others. I often bring my 4.5-inch reflector/60x eyepiece rig to public star parties when the Moon is in the sky. After demonstrating how to image the Moon with my phone, I invite the attendees to try their luck with their phones. What better souvenir to take home than a personal image of the Moon?

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: a voyage to the Bay of Rainbows. Clear skies!

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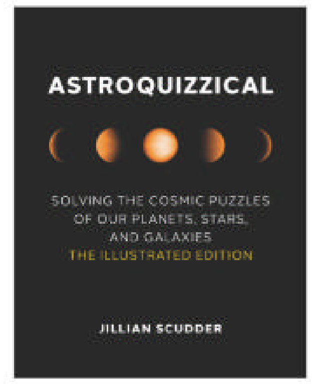
Quizzing an astronomer

MIT Press

Cambridge, Massachusetts

In *Astroquizzical: Solving the Cosmic Puzzles of Our Planets, Stars, and Galaxies: The Illustrated Edition*, astrophysicist Jillian Scudder takes readers on a question-driven journey of the cosmos. In 224 pages, she answers questions ranging from "What color is the universe?" to "What would happen if we split the Sun in half?"



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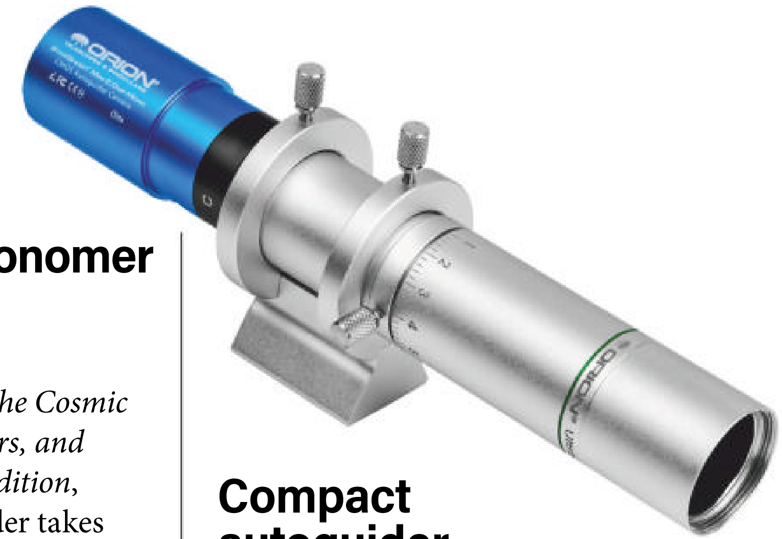

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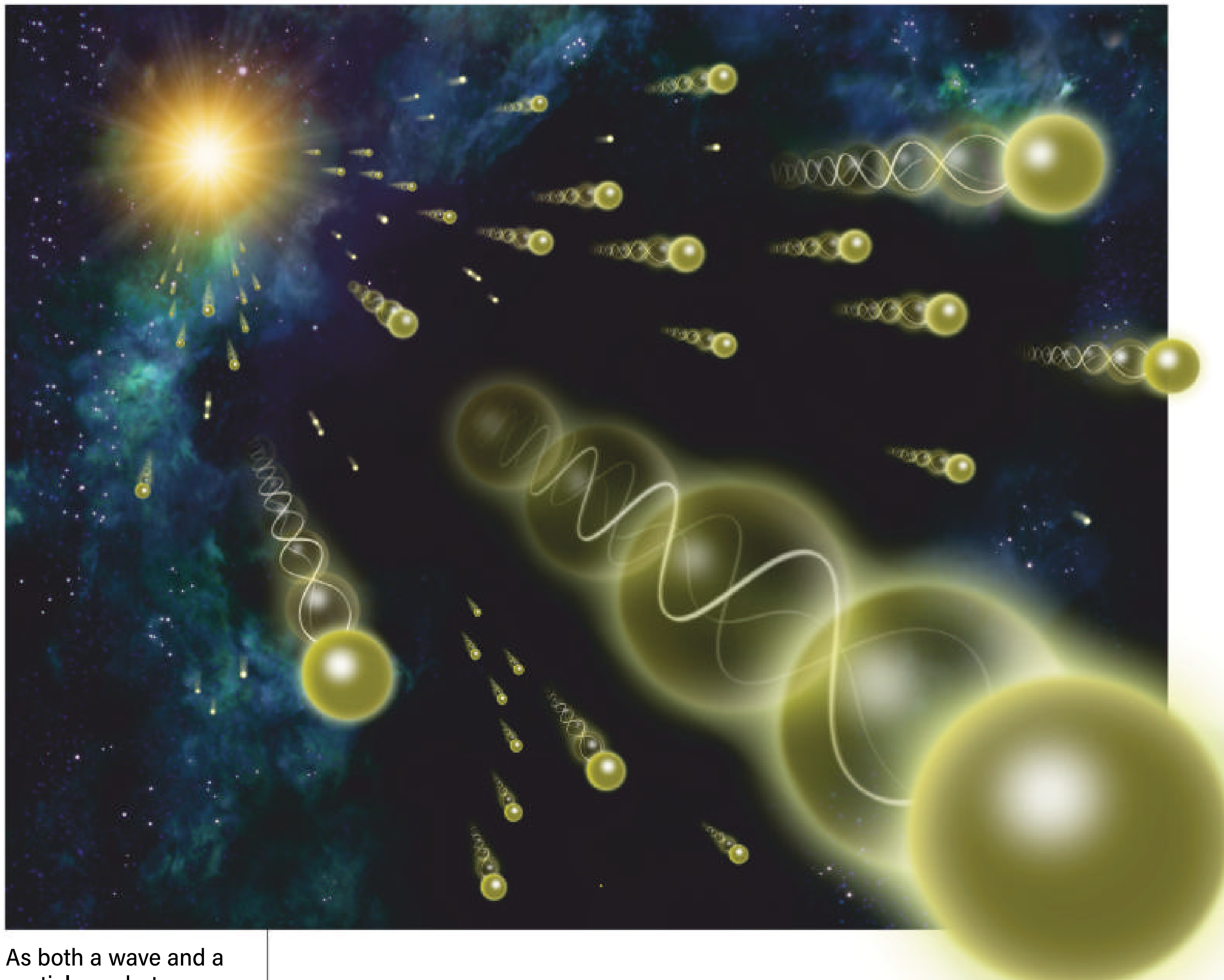


As both a wave and a particle, a photon can have no mass but still carry energy — as long as it has momentum. *ASTRONOMY:* ROEN KELLY

Massless momentum

Q | HOW CAN A PHOTON OF LIGHT CARRY ENERGY BUT ALSO BE CONSIDERED MASSLESS? DOESN'T EINSTEIN'S E = MC² MAKE THAT IMPOSSIBLE?

Robert Bobo
Pullman, Washington

A | Einstein's famous mass-energy equivalence equation, or $E = mc^2$, is actually a special case of a slightly longer formula known as the energy-momentum relation, which is written out as $E^2 = p^2c^2 + m^2c^4$.

This equation relates energy (E) to rest mass (m), the speed of light (c), *and* momentum (p), which is the key to how photons can carry energy but have no mass. When a particle is at rest, it has no momentum and the equation simplifies to the more familiar $E = mc^2$. But if a particle has no mass, the equation becomes $E = pc$.

But wait, you might be asking, how can a particle have momentum without mass? That's where light's duality as both a wave and a particle comes into play. Unlike a particle, whose momentum is related to its mass, a wave's momentum comes solely from its motion, meaning that it can carry momentum even without mass.

Interestingly, something that has neither mass or momentum has no energy, which means it is nothing at all — i.e., it cannot exist. But photons do exist, so it follows that they can never be at rest. And the only speed that remains the same in every reference frame is the universal speed limit (c). Light isn't the only massless particle, however. Gluons, massless particles inside atoms, also travel at the speed of light.

Caitlyn Buongiorno
Associate Editor

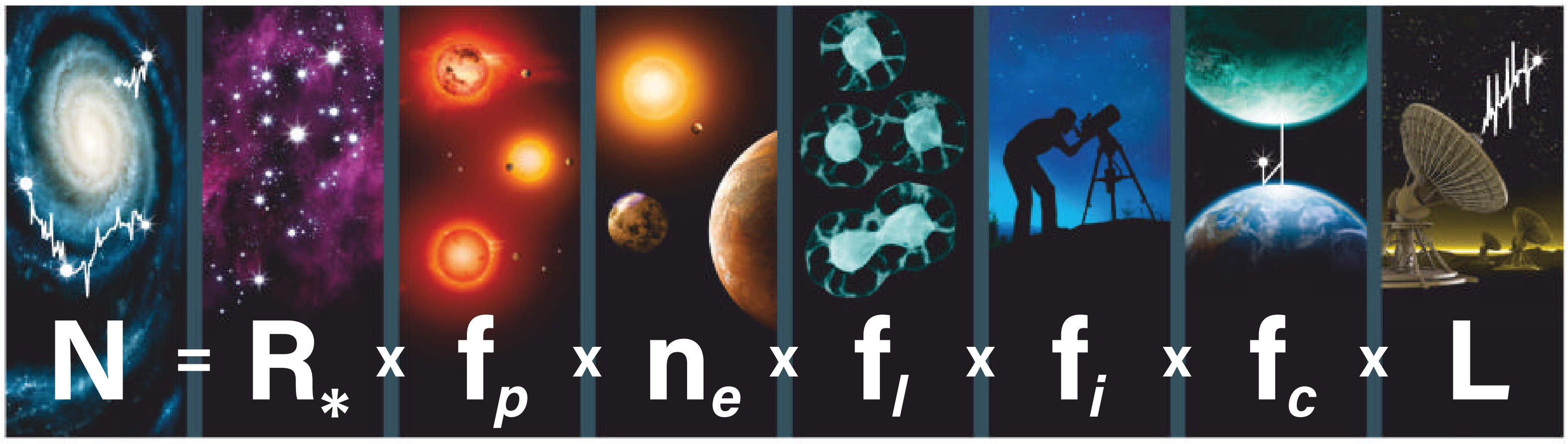
Q | IF THE SOLAR SYSTEM IS ONLY 4.6 BILLION YEARS OLD BUT THE UNIVERSE HAS EXISTED FOR 13.8 BILLION YEARS, ISN'T IT LIKELY THAT OTHER FORMS OF LIFE EXISTED WELL BEFORE US IN THE UNIVERSE?

Bob Spangler
Fruita, Colorado

A | With estimates suggesting there are more than 10 billion terrestrial planets in the Milky Way and several hundred billion galaxies in the observable universe, it seems statistically unlikely that lightning only stuck once when it comes to life. Because we only currently know of one planet able to sustain life, scientists base their searches off Earth, looking for small, rocky worlds in the habitable zone — where surface liquid can exist — around stars with a few common key elements needed for life: carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur.

Even limiting ourselves to those conditions, as you point out, the universe is significantly older than the Sun, meaning that some intelligent civilization should have existed long before humanity. So, where are all the aliens? Why haven't we received any messages? Scientists call this disparity between the apparent likelihood of the abundance of life versus our utter lack of evidence the Fermi paradox.

We don't yet know why the cosmos appear so



The **number** of technologically advanced civilizations in the Milky Way

The **rate** of **star formation** in the galaxy

The **fraction** of those stars with **planetary systems**

The **number** of planets per solar system with an **environment** suitable for life

The **fraction** of suitable planets on which **life** actually appears

The **fraction** of life-bearing planets on which **intelligent** life emerges

The **fraction** of **civilizations** that develop a technology that releases detectable signs of their existence

The **length** of time such civilizations release detectable signals

LEFT: The Drake equation is used to estimate the number of advanced civilizations in the Milky Way. Because researchers work with a number of uncertainties within each variable, the equation can never be solved. *ASTRONOMY*: ROEN KELLY

BELOW: There isn't a scale large enough to weigh galaxies like NGC 7714. ESA, NASA; ACKNOWLEDGEMENT: A. GAL-YAM (WEIZMANN INSTITUTE OF SCIENCE)

deafeningly silent, but plenty of people have proposed hypotheses. One, known as the Great Filter, claims that although intelligent life may evolve frequently, some factor prevents it from lasting long enough for us to observe. This may be the case even for microbial life. Take Mars, for instance, which shows evidence that it could have once hosted such life long ago. Or maybe intelligent life inevitably develops technology faster than it can evolve the ability to use it responsibly, causing advanced civilizations to eradicate themselves. Or random chance may annihilate life — if a nearby supernova, gamma-ray burst, or giant asteroid were to strike Earth, there would be nothing we could do to stop it.

But astronomers are still looking for life because of other arguments like the Drake equation, which estimates the number of active extraterrestrial civilizations at any given time with the capability to communicate. Though the Drake equation can never be accurately calculated, a paper published in 2016 in *Astrobiology* found that as long as the odds of a civilization developing on a habitable planet are greater than about 1 in 10 billion trillion, humanity is not alone in the universe.

Caitlyn Buongiorno
Associate Editor

Q | HOW DO SCIENTISTS WEIGH CELESTIAL OBJECTS?

Mike Sackheim
Evanston, Illinois

A | It's true that you can't simply place a planet or galaxy on a scale to measure how heavy it is. Luckily, astronomers have a few tricks up their sleeves.

The first trick is understanding that gravity and mass are inherently linked. It's important to note that weight — which measures the strength of your local gravitational pull on an object — can change, while mass does not. For example, if you step on a scale on Earth and weigh 150 pounds (68 kilograms), that same scale would read 379 pounds (172 kg) on Jupiter. Your personal mass

isn't what's changing, but your weight changes because more massive planets exert greater gravitational pull on you than less massive ones.

So, to find the mass of an object, astronomers can simply look at how long it takes nearby bodies to orbit that object. Provided they know the distance between the bodies, they can calculate the mass of the central body. In the case of binary stars, astronomers can observe the stars orbiting each other to determine their combined mass. If the stars are nearby and astronomers can see how closely each star orbits their common center of mass, they can determine each star's individual mass. For galaxies it's a little different, but by examining how fast a galaxy is rotating, researchers can similarly determine its mass.

There's another common trick astronomers can use to estimate mass: luminosity. In most cases, a star or galaxy's luminosity — how brightly it shines — is roughly proportional to its mass. So, provided you know one, you can solve for the other. In the case of stars, scientists use computer simulations of how these objects evolve to better understand the relationship between a star's mass and its luminosity — as well as other parameters that can be observed, like temperature and composition.

Caitlyn Buongiorno
Associate Editor

SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Cosmic portraits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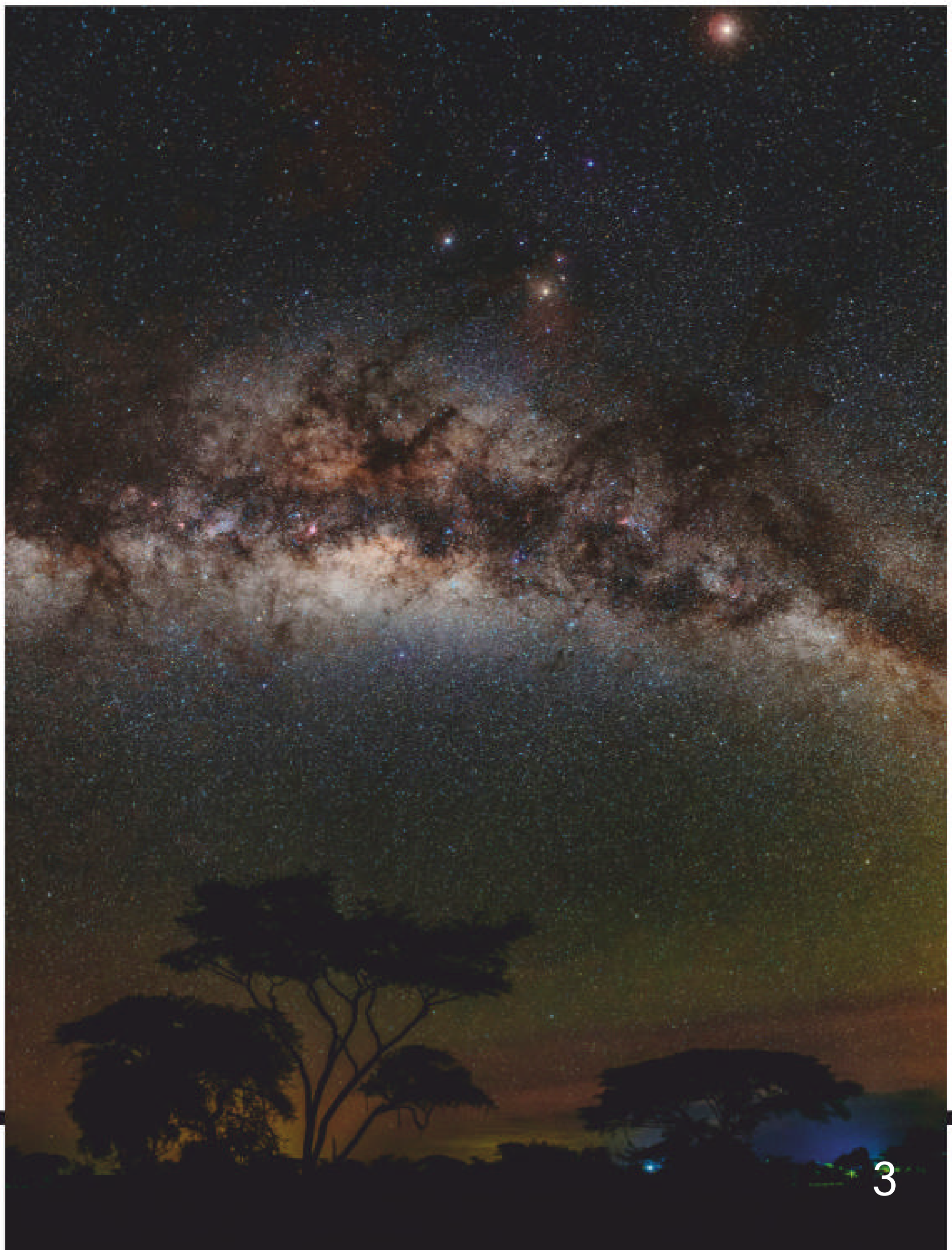
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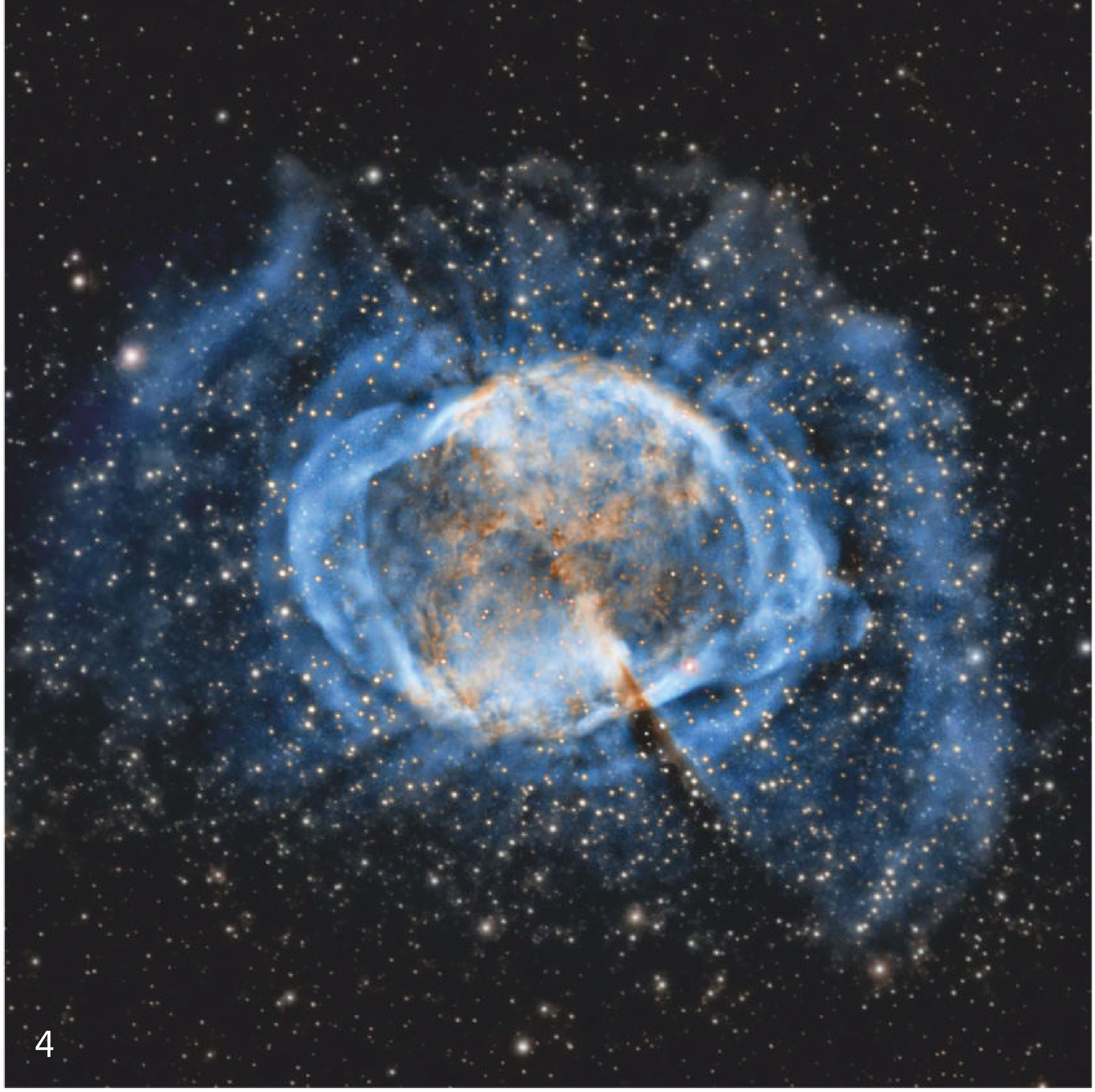
1. CELESTIAL SAFARI
Three nebulous animals are hiding in this cosmic landscape in Cepheus: the Lion (Sh 2–132; bottom), the Elephant's Trunk (part of IC 1396; right), and the Lobster Claw (Sh 2–157; left). The 39-image mosaic is the result of 290 hours of exposure through a 4.2-inch scope, processed in the Hubble palette. **• *Alistair Symon***

2. TWISTING THE BAR
NGC 4731 is a barred spiral galaxy about 40 million light-years distant in the Virgo Cluster that has been distorted by the gravitational pull of the massive elliptical galaxy NGC 4697 (not visible). This LRGB image was taken with a 1-meter scope and 20.5 hours of exposure time. **• *Warren Keller/Mike Selby***

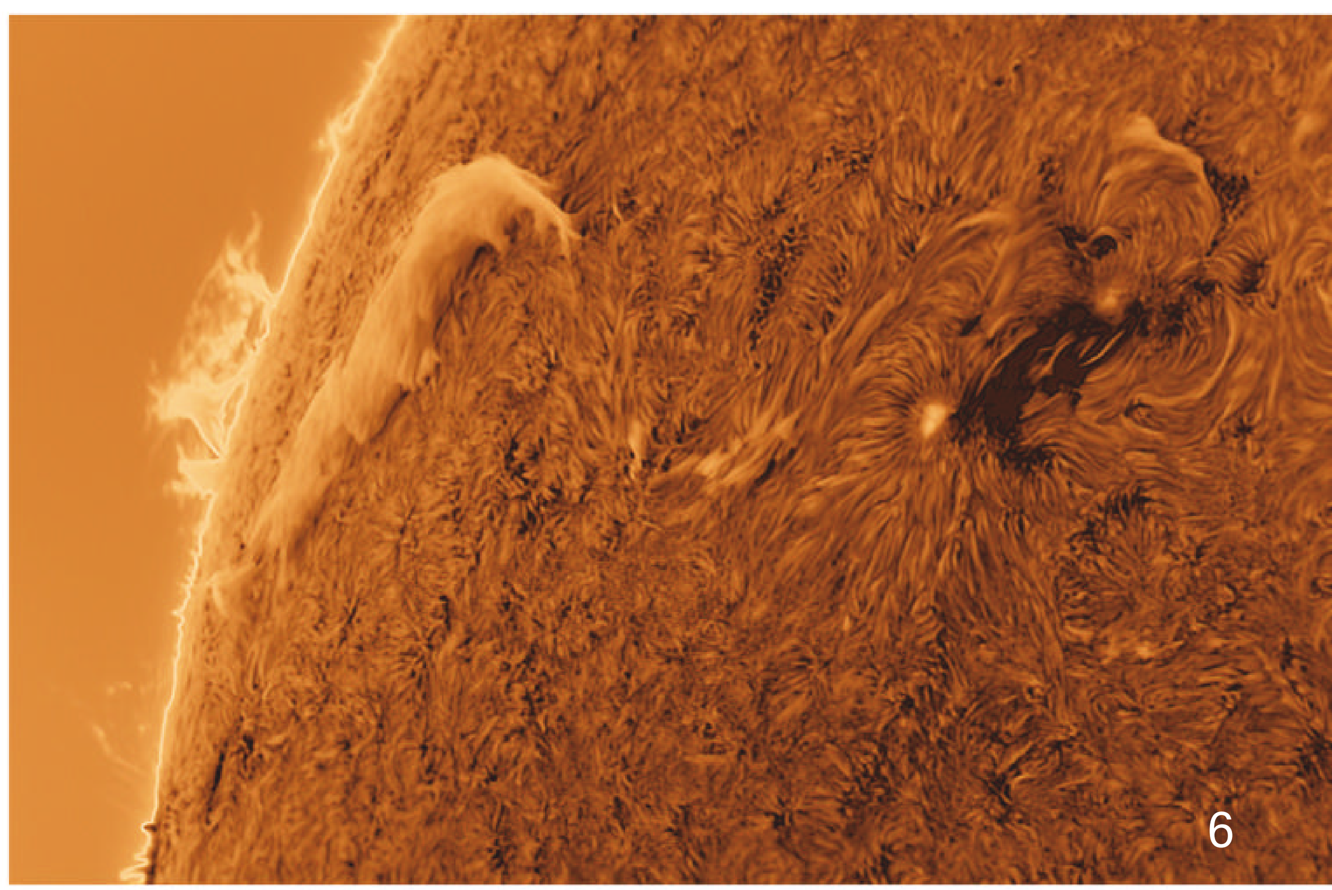
3. TERRESTRIAL SAFARI
The silhouettes of acacia trees in Kenya's Amboseli National Park lie beneath the Milky Way's central bulge. Just above the galaxy's dust lanes shine Saturn and Antares, while Mars glows at upper right. The image is a 15-second exposure on a modified Canon EOS 5D Mark II with a 24mm lens at f/2.2 and ISO 3200. **• *Amirreza Kamkar***



4. DUMBBELL AND SOME SHELLS
The famous Dumbbell Nebula (M27) is surrounded by magnificent shells and an outer halo in this heavily processed image taken in Hubble filters. Clever use of a synthetic luminance image created from a blend of Hα and OIII data reveals structure that is often hidden in RGB images. The image represents 10¼ hours of exposure with a 5-inch scope. **• *Patrick A. Cosgrove***

5. TOUCHING THE MOON
A Full Moon rises over the Giralda in Badajoz, Spain — a 20th-century building that features a replica of the 16th-century belfry of the Seville Cathedral. **• *Sérgio Conceição***

6. SOLAR MEDUSA
A solar filament snakes across the surface of the Sun on Nov. 28, 2021 — a sign that activity in solar cycle 25 is picking up. Because the gas in filaments is cooler than that on the Sun's surface, they usually appear as dark shadows, but this Hα image is inverted to show detail, rendering filaments and sunspots as bright patches. **• *Arturo Javier Buenrostro***



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SINUOUS JETS SNAKE THROUGH SAGITTARIUS

Stars often begin their lives in spectacular fashion, and the gracefully curving arms of MHO 2147 present a vivid example. Clouds of molecular hydrogen light up at infrared wavelengths as they interact with twin torrents of ionized gas ejected from the newly forming star. (The star itself — IRAS 17527–2439 — remains hidden behind the fingerlike dark cloud near the image's center.) MHO 2147's sinuous shape arises because the jets have meandered over time. Astronomers suspect that IRAS 17527–2439 belongs to a triple-star system, and the gravitational influences of these companions cause the directional change. Researchers captured MHO 2147, which lies about 10,500 light-years from Earth, with the 8.1-meter Gemini South Telescope on Cerro Pachón in Chile. INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF/AURA

July 2022

Gas giants take center stage

Although bright planets continue to avoid the early evening sky, the viewing situation improves dramatically in the ensuing hours. And best of all, the first solar system world to appear happens to be the favorite of many observers.

Saturn rises in the east around 9 P.M. local time in early July and some two hours earlier by month's end. The ringed planet resides in eastern Capricornus, where it moves slowly westward (retrograde) relative to the Sea Goat's stars. It passes 1.5° north of magnitude 2.8 Delta (δ) Capricorni, the constellation's brightest star, during July's second week. At magnitude 0.4, Saturn shines nine times brighter than its companion. The planet's retrograde motion signals that opposition is approaching. It will reach this point of peak visibility in mid-August.

Saturn climbs high enough to deliver stunning telescopic views within two hours after rising. Even small scopes at low magnifications show the ring system nicely. At midmonth, the rings span 42" and tip 13° to our line of sight. Centered within the rings lies Saturn itself — an oval disk measuring 18" across the equator.

An even brighter planet enriches the late evening sky by midmonth. **Jupiter** rises around 12:15 A.M. local time July 1 and a half-hour earlier each week thereafter. It brightens from magnitude –2.4 to magnitude –2.6 during July, making it the sky's most dominant point of light until Venus rises before dawn. Jupiter spends the month in a corner of the non-zodiacal constellation Cetus the Whale, beginning its own retrograde loop July 29 in anticipation of a late September opposition.

Jupiter's disk appears noticeably flattened when viewed through a telescope. It's equatorial diameter spans 42.7" at midmonth while the polar diameter measures only 40.0". Look for intricate details in the giant planet's atmosphere during moments of good seeing. Also take some time to admire Jupiter's four bright Galilean moons: Io, Europa, Ganymede, and Callisto.

While Saturn's and Jupiter's visibilities improve markedly during July, **Mars** operates on a slower schedule. It rises at 1:45 A.M. local time July 1 and only about 25 minutes earlier by month's end. The Red Planet crosses from Pisces the Fish into Aries the Ram on July 8. Shining at magnitude 0.3 at midmonth, it easily outpaces the stars in these constellations.

Despite its slow progress, Mars continues to pull steadily closer to Earth and thus looks larger through a telescope. Its 8"-diameter disk should show some subtle details through medium-sized scopes during moments of good seeing.

Venus rises a bit more than two hours before the Sun in early July. That gives you plenty of time to enjoy a rare celestial alignment on the 1st, when the brilliant planet becomes the second eye of Taurus the Bull. Blazing at magnitude –3.9, Venus shines nearly 100 times brighter than the Bull's permanent eye: 1st-magnitude Aldebaran. The planet's westward motion against the stars carries it through northern Orion the Hunter for 50 hours in mid-July before it moves into Gemini the Twins for the rest of the month. When viewed through a telescope, Venus spans 11" and appears about 90 percent lit.

You might catch a glimpse of **Mercury** in the northeast shortly before dawn in early July or in the west-northwest at dusk late in the month, but the planet's low altitude makes observations difficult. You'll be better off waiting for the inner world's best evening appearance of the year in August.

The starry sky

As twilight fades to darkness these July evenings, the constellations of the zodiac span from Cancer the Crab in the west-northwest to Capricornus the Sea Goat in the east-southeast. These star patterns follow the ecliptic plane, the apparent path of the Sun across our sky that coincides with the projection of Earth's orbit onto the celestial sphere.

When the International Astronomical Union adopted official constellation borders in the 1920s, the length of the ecliptic in each constellation varied. Our current evening sky boasts the constellations having both the longest and shortest ranges of ecliptic longitudes cutting through them: Virgo and Scorpius, respectively. This naturally corresponds to the longest and shortest amounts of time that the Sun spends within their borders.

Astronomers measure longitude along the ecliptic starting from the Sun's position at the vernal equinox (in Pisces), the point where the ecliptic crosses the celestial equator moving from south to north.

The ecliptic enters Virgo at a longitude near 174° some 3° west of Beta (β) Virginis. It then passes slightly south of Gamma (γ) Vir and a bit north of Virgo's brightest star, 1st-magnitude Spica, before exiting the Maiden 1° southeast of Lambda (λ) Vir at a longitude of 218°. So, an ecliptic span of 44° lies in Virgo. Virgo wins the prize for the biggest expanse because it is the second-largest constellation and the ecliptic passes almost centrally through its length.

Scorpius tells a much different story. The ecliptic enters the Scorpion 0.6° east-southeast of Lambda Librae and exits it just 7° later some 2° west of Omega (ω) Ophiuchi. Scorpius wins the booby prize despite ranking a respectable 33rd in size among the 88 constellations. Its downfall arises because, even though it is a sprawling constellation, the ecliptic cuts through its narrow northern section.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. July 1
8 P.M. July 15
7 P.M. July 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

JULY 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

2 Venus passes 4° north of Aldebaran, 0h UT

4 Earth is at aphelion (152.1 million kilometers from the Sun), 7h UT

7 First Quarter Moon occurs at 2h14m UT

12 Asteroid Vesta is stationary, 6h UT

13 The Moon is at perigee (357,264 kilometers from Earth), 9h06m UT

Full Moon occurs at 18h38m UT

15 The Moon passes 4° south of Saturn, 20h UT

16 Mercury is in superior conjunction, 20h UT

18 The Moon passes 3° south of Neptune, 1h UT

19 The Moon passes 2° south of Jupiter, 1h UT

20 Pluto is at opposition, 2h UT

Last Quarter Moon occurs at 14h19m UT

21 The Moon passes 1.1° north of Mars, 17h UT

22 Dwarf planet Ceres is in conjunction with the Sun, 1h UT

The Moon passes 0.2° north of Uranus, 6h UT

26 The Moon is at apogee (406,274 kilometers from Earth), 10h22m UT

The Moon passes 4° north of Venus, 14h UT

28 Asteroid Juno is stationary, 10h UT

New Moon occurs at 17h55m UT

29 Jupiter is stationary, 12h UT

30 Southern Delta Aquariid meteor shower peaks